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BALLISTIC WINDS STUDY

QUARTERLY REPORT NO. 3

By

FREDERICK P. OSTBY, JR.

JUNE 1966

ECOM

UNITED STATES ARMY ELECTRONICS COMMAND · FORT MONMOUTH, N.J.

CONTRACT NO. DA 28-043 AMC-01377(E)

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Quarterly Report

Report No. 3

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Prepared by

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ABSTRACT

An objective analysis technique known as CRAM (Conditional Relaxation Analysis Method) has been programmed for the IBM 7090 to compute ballistic winds, temperature, and density over a region of southeastern Arizona in the vicinity of Ft. Huachuca. The various components and available options of the program are described. A set of analyses produced from initial tests is shown and the ballistic quantities derived are compared with those of the previous quarterly report.

Corrections based on a single station (Ft. Huachuca) were applied to concurrent artillery firings for 19 cases. The residual errors derived from these cases will be used as a control for later experiments. The distribution of the residual errors relative to the target strongly suggests a bias in range errors, the average impact location being nearly 200 meters beyond the target.

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1.0 INTRODUCTION

Work in the third quarter centered around the checkout and initial test runs of the CRAM (Conditional Relaxation Analysis Method) objective analysis program. These tests were concerned with variations of forcing functions, initial guesses, relaxation and smoothing procedures, and scaling of the vertical coordinate as applied to the four analysis parameters: u- and v-wind components, temperature, and density.

The associated gun data resulting from the test firings of a pair of 8-inch howitzers are being studied. A small computer program has been written that applies drift and coriolis corrections to a given impact point, and meteorological corrections of ballistic-wind components, temperature, and density. The program was run on a portion of the January—February 1965 data sample. Results are described in Section 3.0.

The third activity of the quarter involved the preparation of a post-processing program that will operate on the output of the objective analysis program. The purpose of this new program is to compute ballistic corrections, error fields, and certain statistical summaries of the data.

2.0 OBJECTIVE ANALYSIS EXPERIMENTS

2.1 Description of CRAM Program

CRAM is the principal analysis tool for this study to provide analyzed maps of winds, temperature, and density. The main components of the CRAM program are: (a) the initial-guess technique, (b) correction procedures, (c) relaxation methods, (d) smoothing, and (e) ballistic computation. The description of these components that follows points out the features of this IBM 7090 program.

2.1.1 The Initial Guess

CRAM requires the use of an initial-guess field, which undergoes subsequent corrections. In principle, the initial-guess field can be generated in a variety of ways. Two rather reasonable approaches are to apply a surface-fitting technique to the data or to use the previous analysis (e.g., two hours earlier), if one is available, or some combination or "blend" of the two approaches. Our version of the program uses these surface fitting and persistence approaches.

In the surface fitting procedure, the three-dimensional surface is sought which best fits the observed field of data. The equation is of the form

$$\phi = a_0 + a_1x_1 + a_2x_2 + a_3x_3 + \dots + a_px_p \qquad (2\text{-}1)$$

where the dependent variable ϕ is the variable to be analyzed over an evenly-spaced field of grid points, the a's are the coefficients and the x's are the independent variables which are functions of the locations of the observations of ϕ, i.e., x, y, and z. Because there are a large number of terms that can be generated from the possible combinations of x, y, and z, many of which may not be significant in explaining the variability of ϕ, it seems reasonable to attempt to reduce the number of possible "predictors" through the use of a systematic, stepwise screening procedure. The method chosen is that of screening regression. From an array of possible predictors (x, y, z, xy, xz, etc.), the screening procedure first selects the one that has the highest linear correlation with the predictand in question. This predictand is then held constant, and partial-correlation coefficients between the predictand and each of the remaining predictors are examined; the predictor now associated with the highest coefficient is the second one selected. Additional predictors are chosen similarly until a selected predictor fails to explain a significant additional percentage of the remaining

variance of the predictand. The coefficients (a_0, a_1, etc.) are then derived by the method of least squares. The initial-guess field is then generated by solving the derived equation at each of the grid points in the analysis volume.

The program is written such that it is possible to compute an initial guess from a blend of persistence and surface fitting. This is done to incorporate continuity, as the observations are taken at two-hour intervals on alternate days between 0600 and 1400 MST. For the first observation time of the day (0600 MST), however, no weight is given to persistence because the previous available observation is usually forty hours old. The formula used in the program to calculate the initial-guess value of ϕ at a grid point is

$$\phi_{I.G.} = \frac{1}{1+W_p} \phi_{\text{surface fit}} + \frac{W_p}{1+W_p} \phi_{\text{persistence}} \tag{2-2}$$

where W_p = weight of persistence. By assigning a value of zero to W_p, persistence is given no weight and the initial guess is based solely on the surface fit. A value of one for W_p assigns half the weight to each while a very large value of W_p essentially gives all the weight to persistence.

2.1.2 Correction Procedures

After it is determined, the initial-guess field is "corrected". For each observation, the difference between the observed value and the value computed for that location by interpolating among the initial-guess values at the surrounding grid points is computed. This difference is then translated to the nearest grid point and added to that grid point as a correction to the initial guess. When a grid point is subject to multiple corrections (from several different observations), an overall correction is computed as the arithmetic average of the several individual corrections.

2.1.3 Relaxation Methods

The relaxation process is the next step in the objective analysis procedure. We compute for all grid points, except those on the boundaries and those which have been corrected by data, new values that satisfy the Poisson equation,

$$\nabla^2 \phi(i, j, k) = F(i, j, k) \tag{2-3}$$

where ϕ is the value of the analysis parameter at grid point (i, j, k), F is a forcing function which may define some specified feature of the field of ϕ, and ^{2} is the finite-

difference Laplacian operator in three dimensions. The Laplacian of a good initial-guess field provides a good forcing function. In the program, the formula is written as follows:

$$\nabla^2\phi(i,j,k) = \phi(i+1,j,k) + \phi(i-1,j,k) + \phi(i,j+1,k) + \phi(i,j-1,k) - 4\phi(i,j,k) + K_A[\phi(i,j,k+1) - \phi(i,j,k)] - K_B[\phi(i,j,k) - \phi(i,j,k-1)] \tag{2-4}$$

where K_A and K_B are coefficients pertaining to the vertical gradient computed above and below the analysis grid point, respectively.

The horizontal and vertical space gradients have been expressed separately in this equation. There are several practical reasons for doing this, all having to do with the scaling of the vertical coordinate used in the analysis technique. The basic horizontal grid length is 10 km, while in the vertical the grid length is about an order of magnitude smaller. Measuring gradients over this smaller distance is generally compensated for by the fact that, for most atmospheric variables, the vertical gradients are much larger than the horizontal gradients so that one may be justified in using $K_A = K_B = 1$ in Eq. (2-4). The relative inequalities between the grid distances above and below the grid point which arise from the uneven spacing of the artillery zones may be accounted for by assigning different values to K_A and K_B. Also, it is possible in the program to consider the objective analysis problem in a two dimensional framework by simply setting $K_A = K_B = 0$.

The solution of Eq. (2-3) is accomplished by relaxation methods. For each of the grid points where new values are being computed, the residual, R, is computed by

$$R(i,j,k) = \nabla^2\phi(i,j,k) - F(i,j,k). \tag{2-5}$$

New estimates of ϕ are then computed by

$$\hat{\phi}(i,j,k) = \alpha R(i,j,k) + \phi(i,j,k) \tag{2-6}$$

where α, a relaxation coefficient, is an input parameter. New residuals are then computed. The iterative procedure continues until all residuals are less than a specified value (ϵ).

2.1.4 Smoothing

A smoothing operator has been developed which is designed to eliminate from the analysis undesirable small-scale features. The expression used is

$$
\begin{aligned}
S[\phi(i,j,k)] = W_1\,\phi(i,j,k) &+ W_2[\phi(i+1,j,k) + \phi(i-1,j,k) \\
&+ \phi(i,j+1,k) + \phi(i,j-1,k)] \\
&+ W_3[\phi(i,j,k+1) + \phi(i,j,k-1)],
\end{aligned}
\tag{2-7}
$$

$$
\left(W_1 = \frac{6}{6 + 4B_h + 2B_v};\; W_2 = \frac{B_h}{6 + 4B_h + 2B_v};\; W_3 = \frac{B_v}{6 + 4B_h + 2B_v} \right)
$$

The parameters B_h and B_v control the degree of smoothing to be performed. A value of zero assigned to each results in the entire weight being given to $\phi(i,j,k)$, i.e., no smoothing. Large values of B_h and B_v result in heavy smoothing. Also, the smoothing can be restricted to two dimensions by setting $B_v = 0$.

2.1.5 Ballistic Computation

The CRAM Program produces analyses of u- and v-wind components, temperature, and density for each of ten artillery zones. These zones are listed in Table 2-1 for an analysis area 17 grid units in the I-direction (from I=50 to I=66) and 15 grid units in the J-direction (from J=345 to J=359) or about 170 km x 150 km. A portion of this grid is shown in Fig. 2-1. The analysis area is purposely made large so that analysis problems associated with the boundaries are far enough removed to not contaminate the analysis in the region of interest, i.e., near the firing area. The ballistic fields are produced within the program by applying the zone weighting factors that are given in Table 2-1. A minor modification in the program will permit ballistic computations of "lines" other than merely line 10.

2.2 Analysis Examples

The five time periods of 25 January 1965 were chosen to illustrate the CRAM Program. This is the same data sample that was analyzed by hand and reported in the previous quarterly report*. Results of these analyses should be considered as being

*Ostby, F. P., 1966: Ballistic Winds Study, Quarterly Report No. 2, Contract No. DA 28-043 AMC-01377(E), The Travelers Research Center, Inc.

TABLE 2-1
ZONE STRUCTURE AND WEIGHTING FACTORS FOR BALLISTIC COMPUTATIONS (maximum ordinate: 8,000 m)

Zone	Height (m)		Weighting factors*		
	Base	Top	Wind	Temperature	Density
1	Surface	200	0.01	0.00	0.03
2	200	500	0.02	0.01	0.04
3	500	1000	0.02	0.02	0.07
4	1000	1500	0.04	0.02	0.07
5	1500	2000	0.03	0.03	0.07
6	2000	3000	0.07	0.07	0.13
7	3000	4000	0.08	0.13	0.12
8	4000	5000	0.09	0.22	0.11
9	5000	6000	0.09	0.23	0.11
10	6000	8000	0.55	0.27	0.25

*From FM 6-16, Tables for Artillery Meteorology.

of a preliminary nature, with further testing of the program options being required. The analyses are shown in Figs. 2-2 through 2-11.

The initial-guess procedure of blending a surface fit with persistence, described in Section 2.1.1, was not ready in time for this particular set of analyses. An alternate procedure with a four-dimensional surface fit incorporating time (t) was used. The screening regression technique was applied to parameters generated from various combinations of x, y, z, and t. The resulting set of equations showed considerable dependency on the vertical coordinate, with z terms being selected first for each of the four equations.

In these initial tests we have used a forcing function of zero [$F = 0$ in Eq. (2-3)] and have also set $K_A = K_B = 0$ in Eq. (2-4). Testing of the relaxation coefficient, α, indicates that the number of iterations are minimized with $\alpha = 0.22$. The smoothing operator was employed using $B_h = 1.5$ and $B_v = 0$, which give half the weight to the grid point in question and the other half to the average of the four surrounding grid

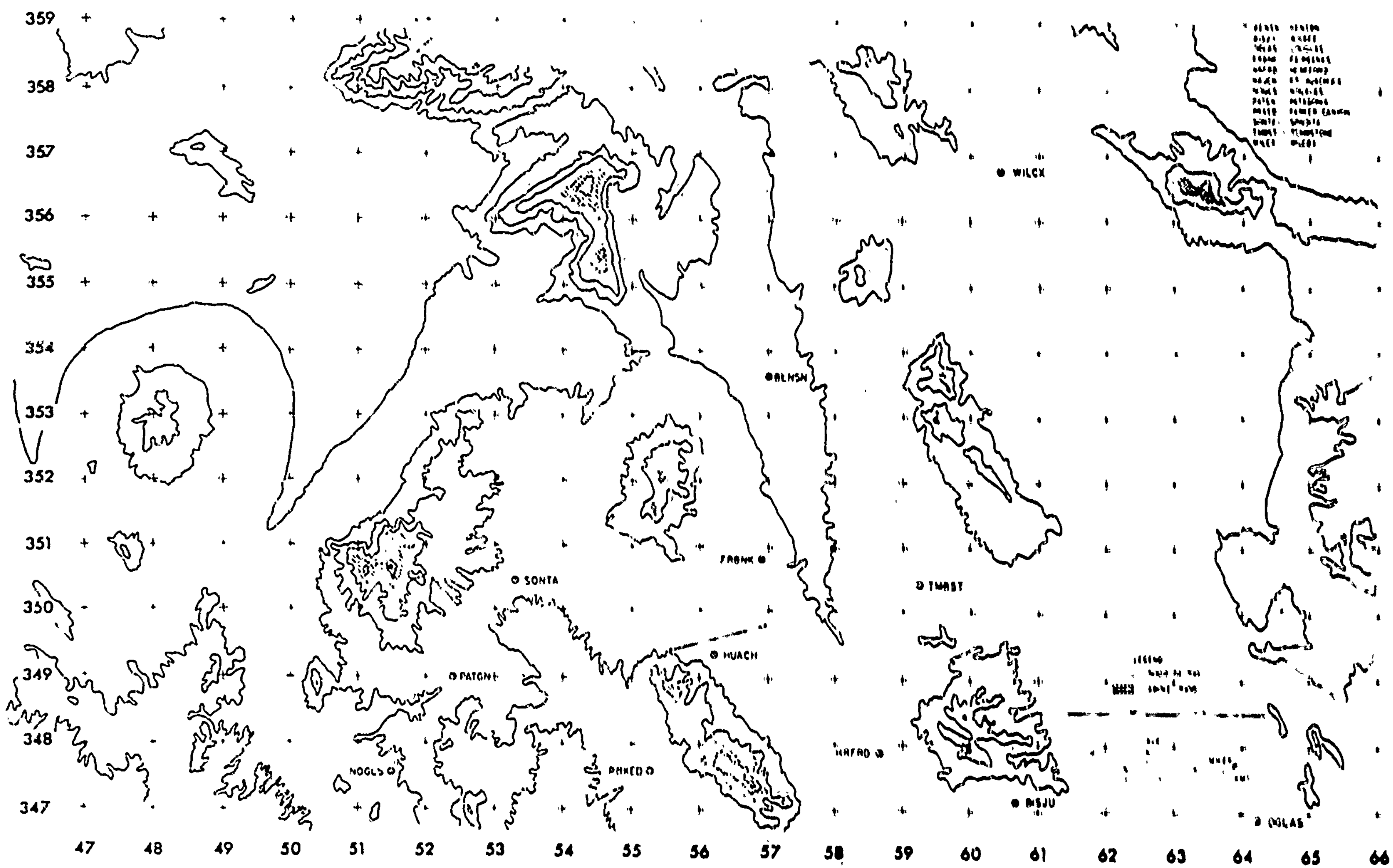

Fig. 2-1. Objective analysis grid showing observing stations. Grid units are based on the 10,000-m Universal Transverse Mercator Grid (Zone 12), with the last four digits of the grid numbers omitted.

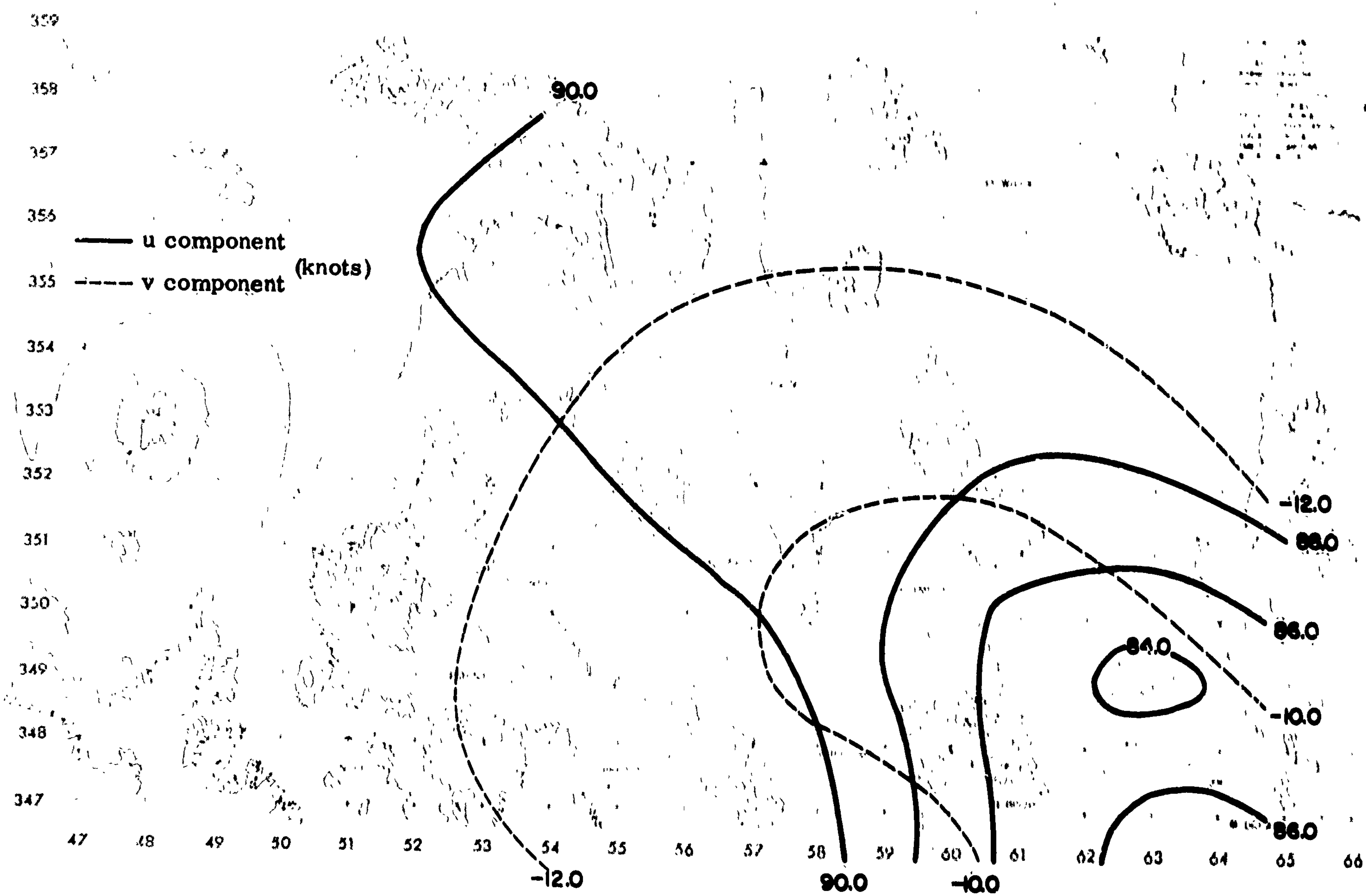

Fig. 2-2. Ballistic wind analysis using CRAM: 0600 MST, 25 January 1965.

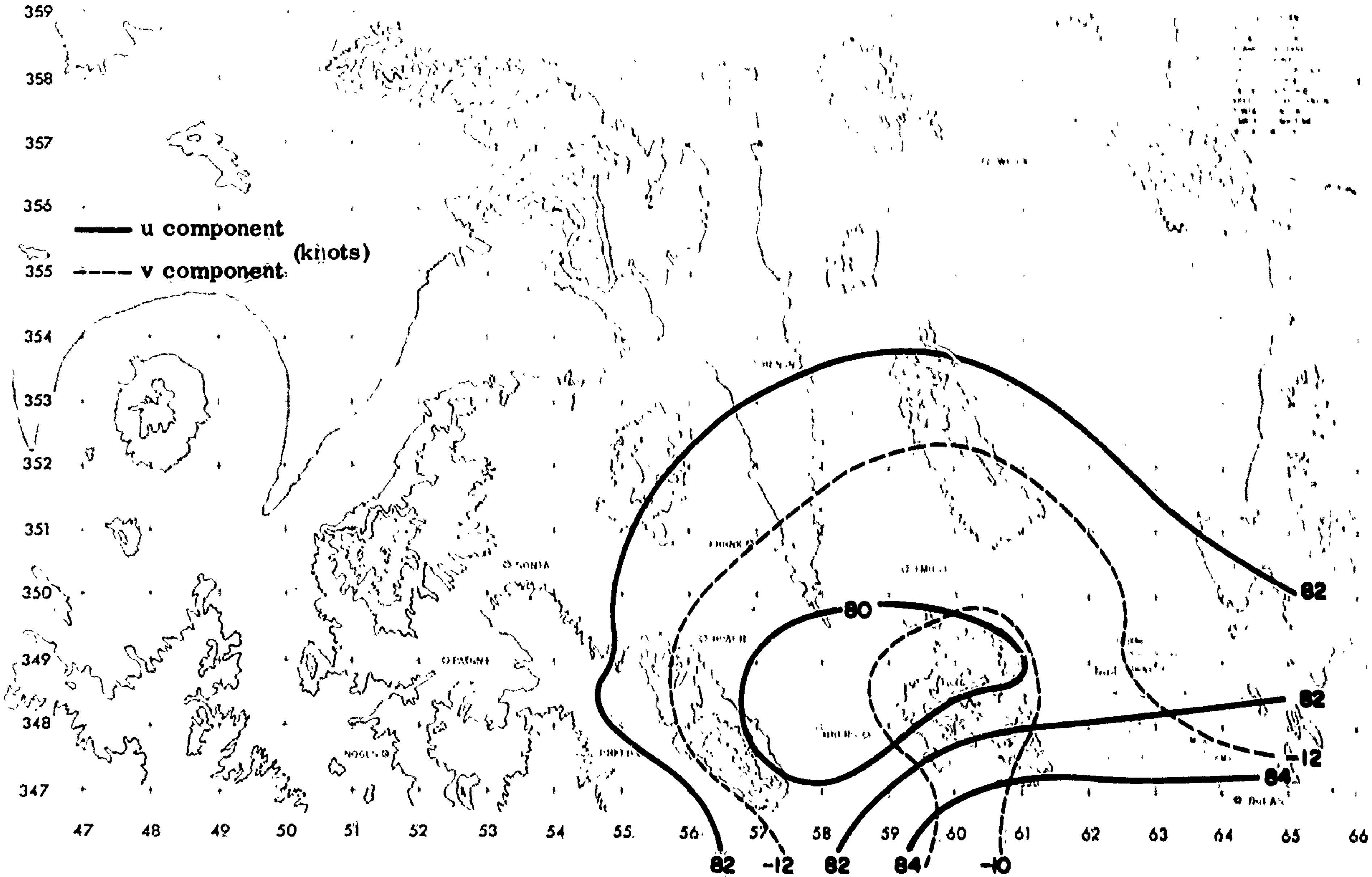

Fig. 2-3. Ballistic wind analysis using CRAM: 0800 MST, 25 January 1965.

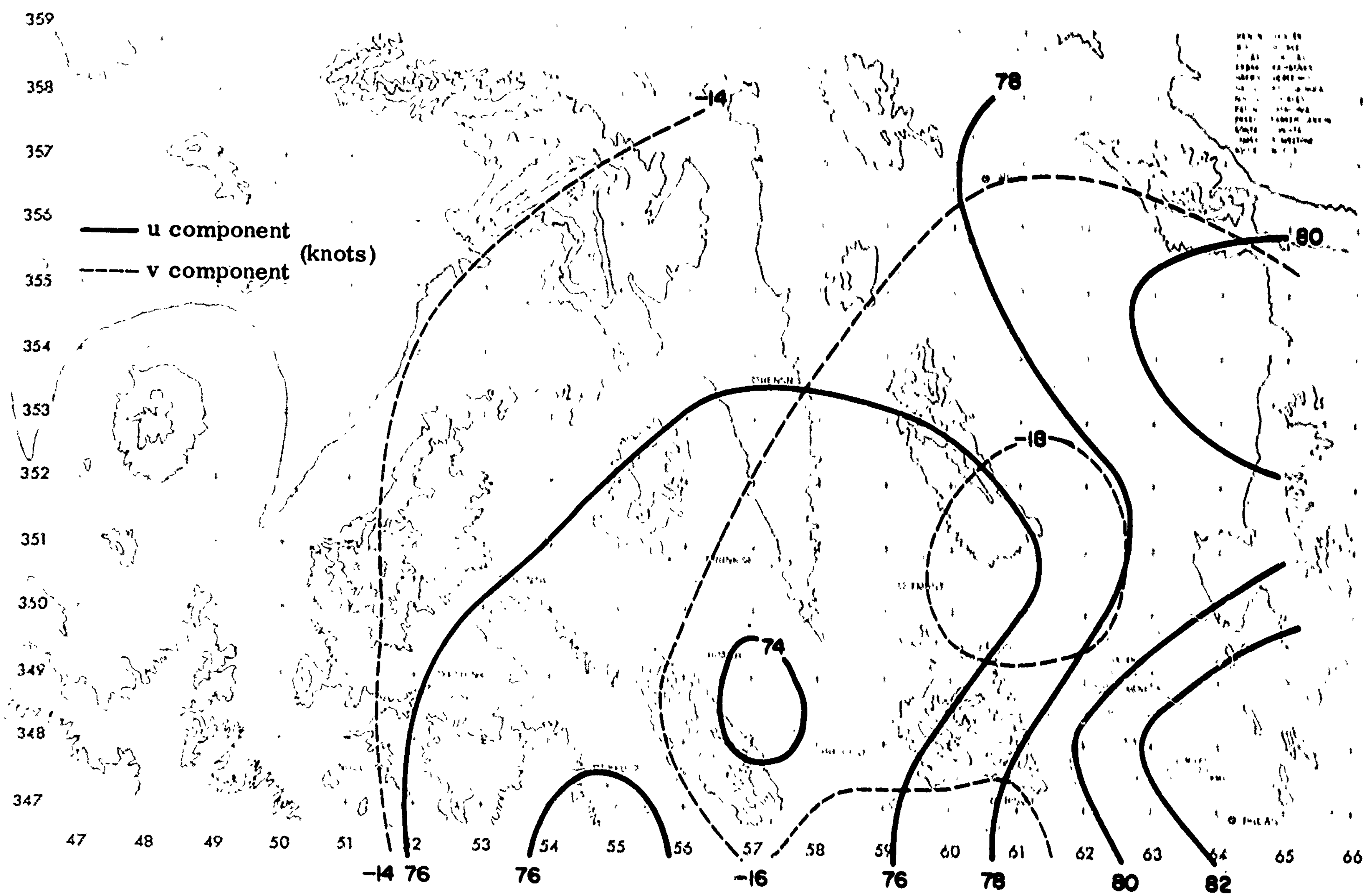

Fig. 2-4. Ballistic wind analysis using CRAM: 1000 MST, 25 January 1965.

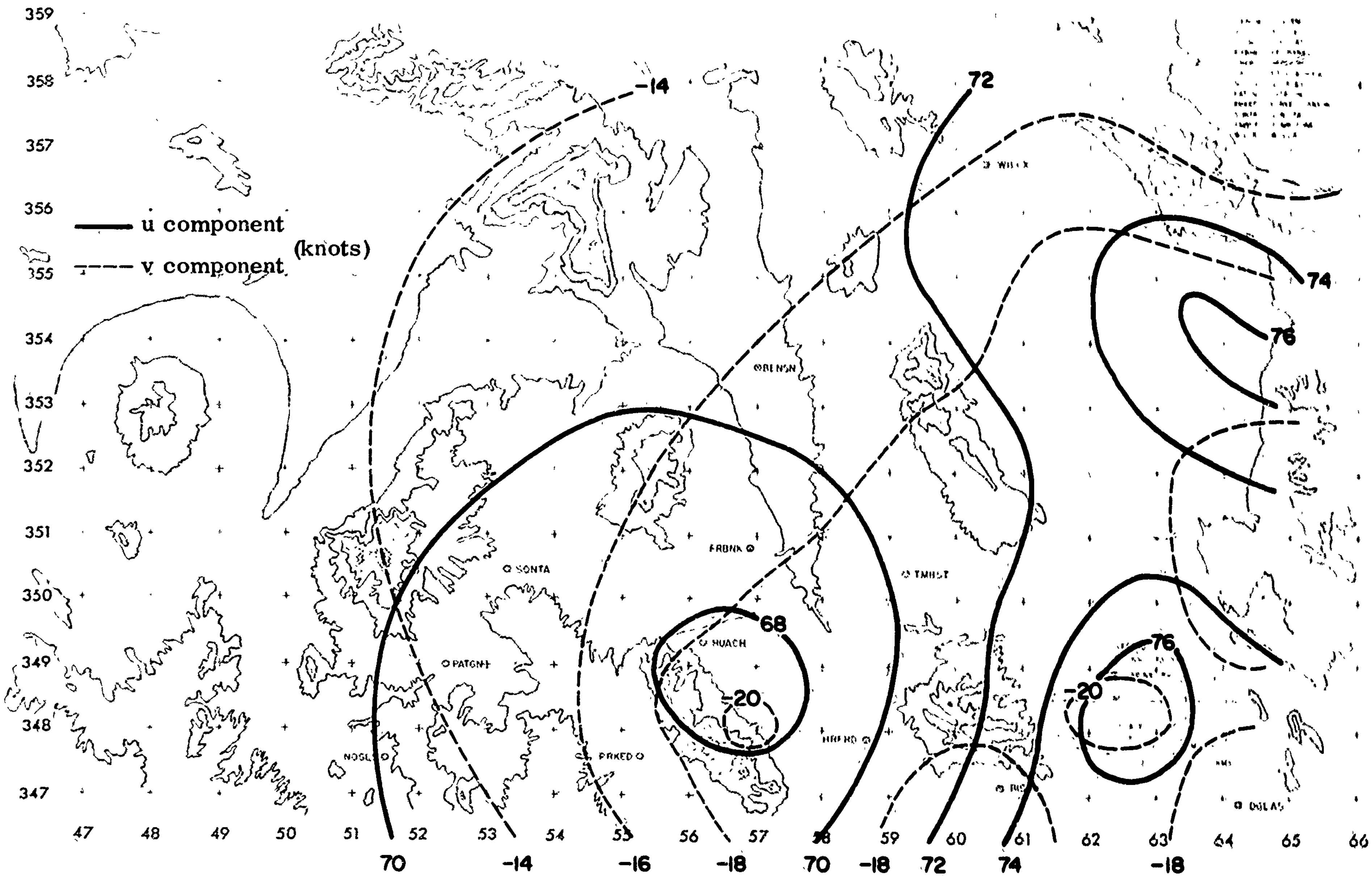

Fig. 2-5. Ballistic wind analysis using CRAM: 1200 MST, 25 January 1965.

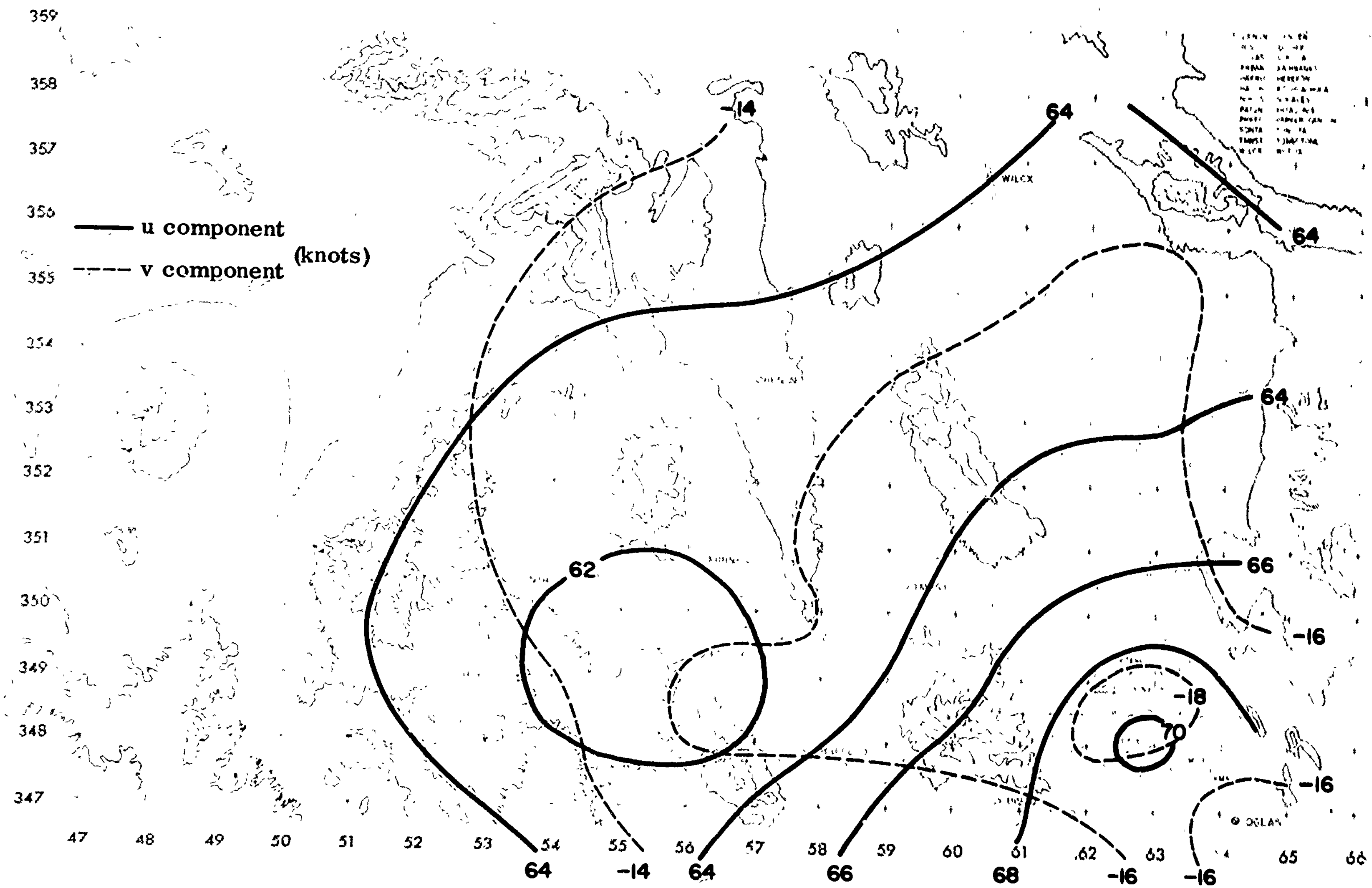

Fig. 2-6. Ballistic wind analysis using CRAM: 1400 MST, 25 January 1965.

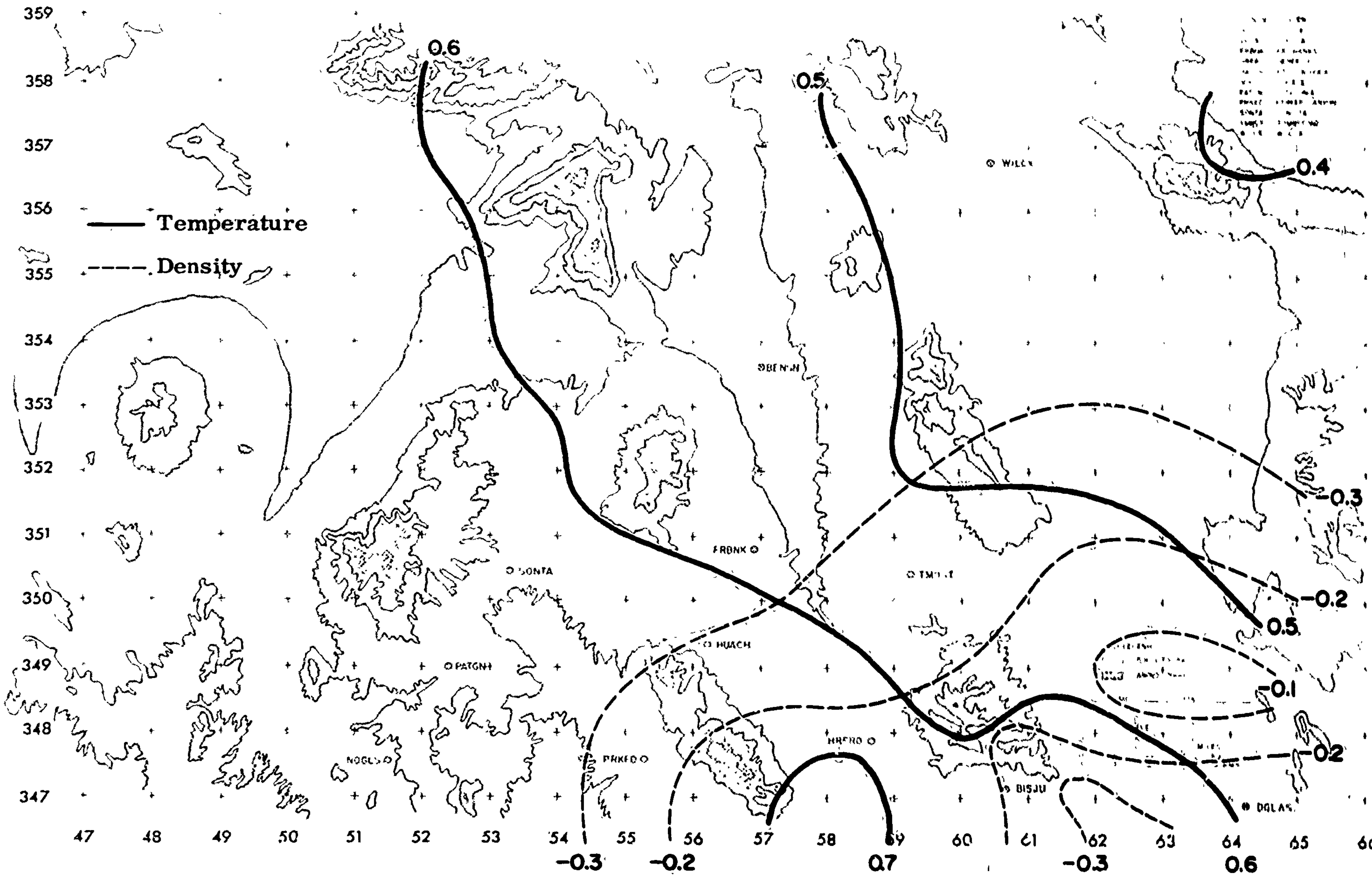

Fig. 2-7. Ballistic temperature and density analysis using CRAM: 0600 MST, 25 January 1965 (percent departure from Standard).

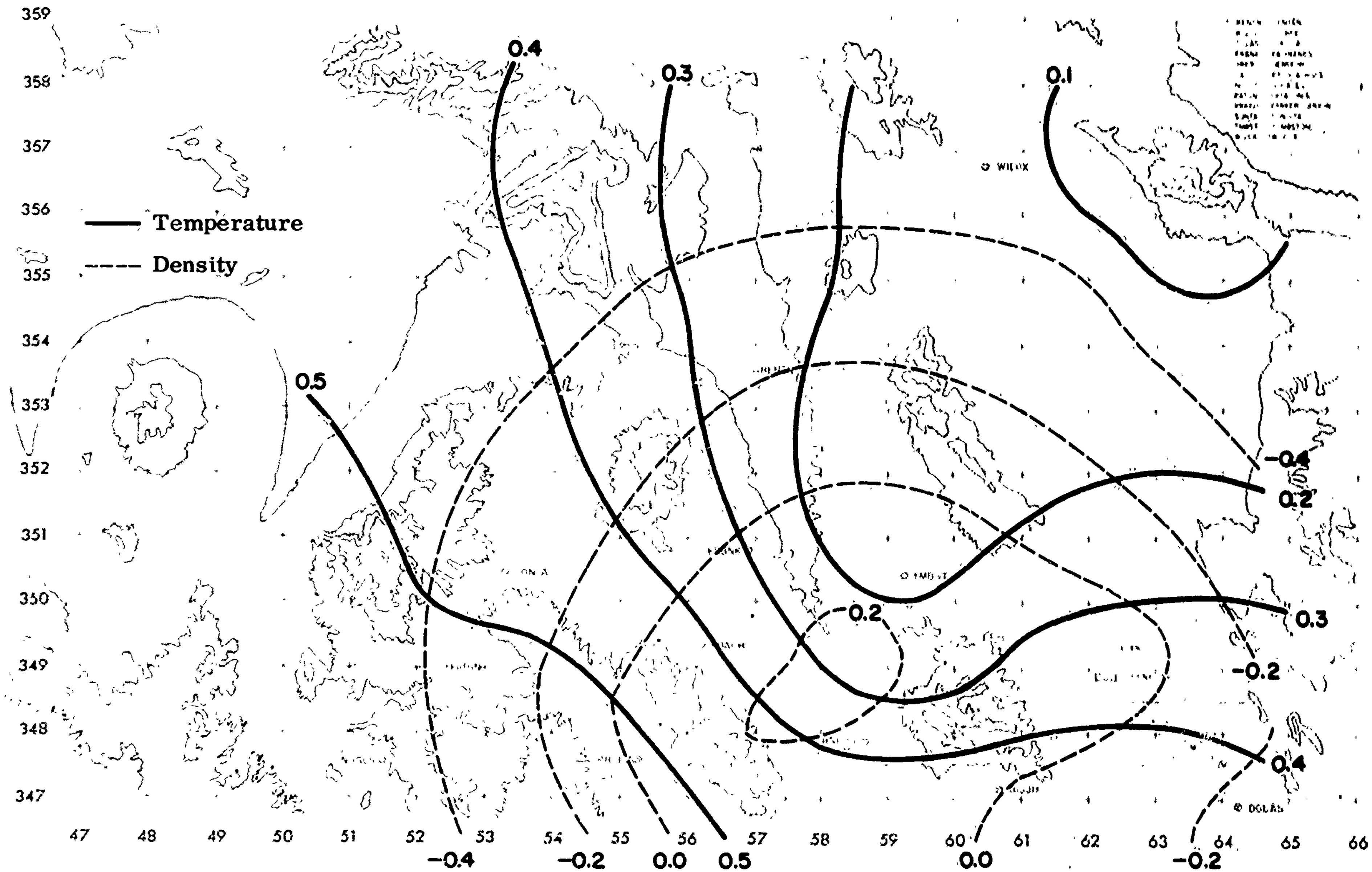

Fig. 2-8. Ballistic temperature and density analysis using CRAM: 0800 MST, 25 January 1965 (percent departure from Standard).

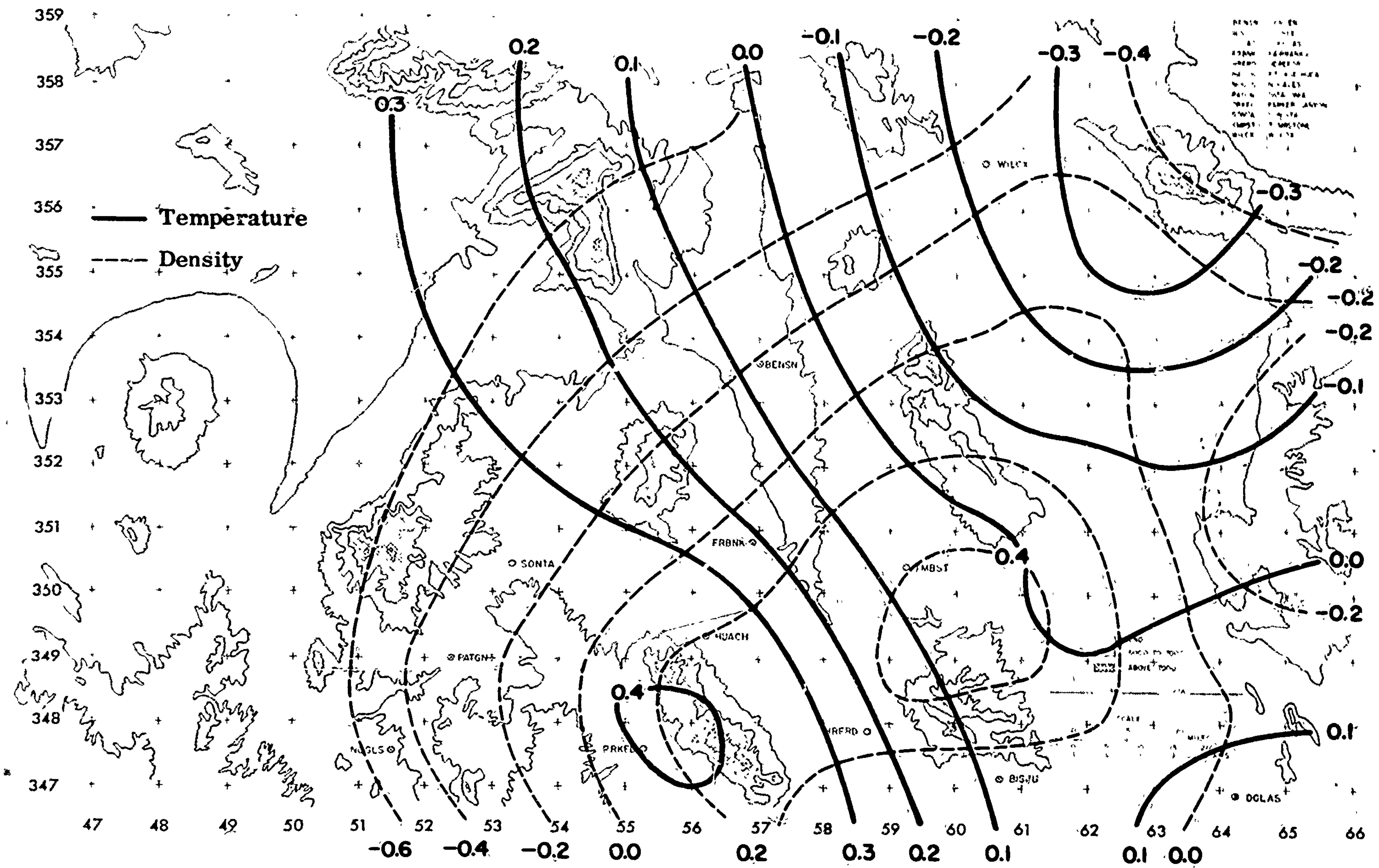

Fig. 2-9. Ballistic temperature and density analysis using CRAM: 1000 MST, 25 January 1965 (percent departure from Standard).

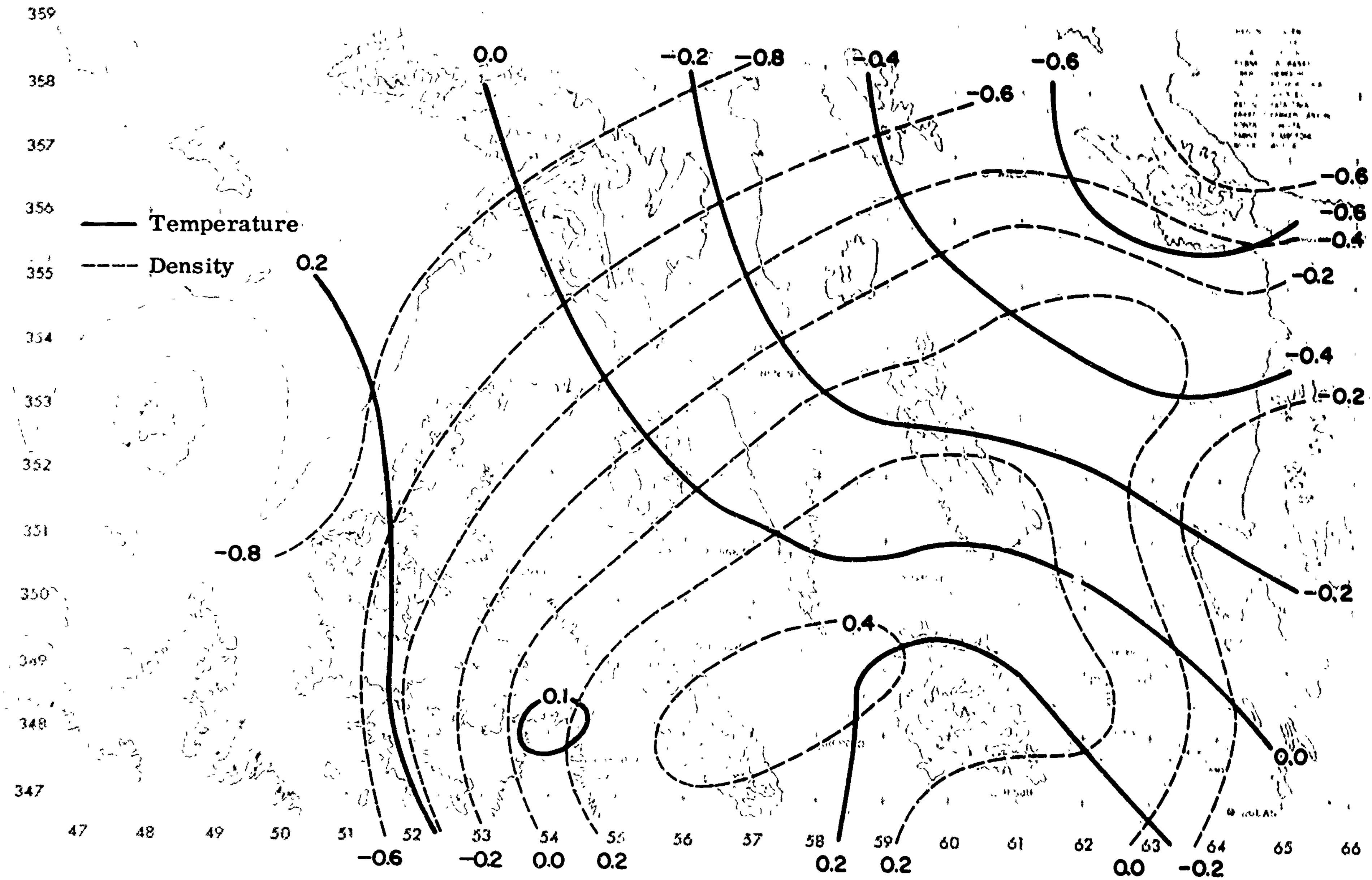

Fig. 2-10. Ballistic temperature and density analysis using CRAM: 1200 MST, 25 January 1965 (percent departure from Standard).

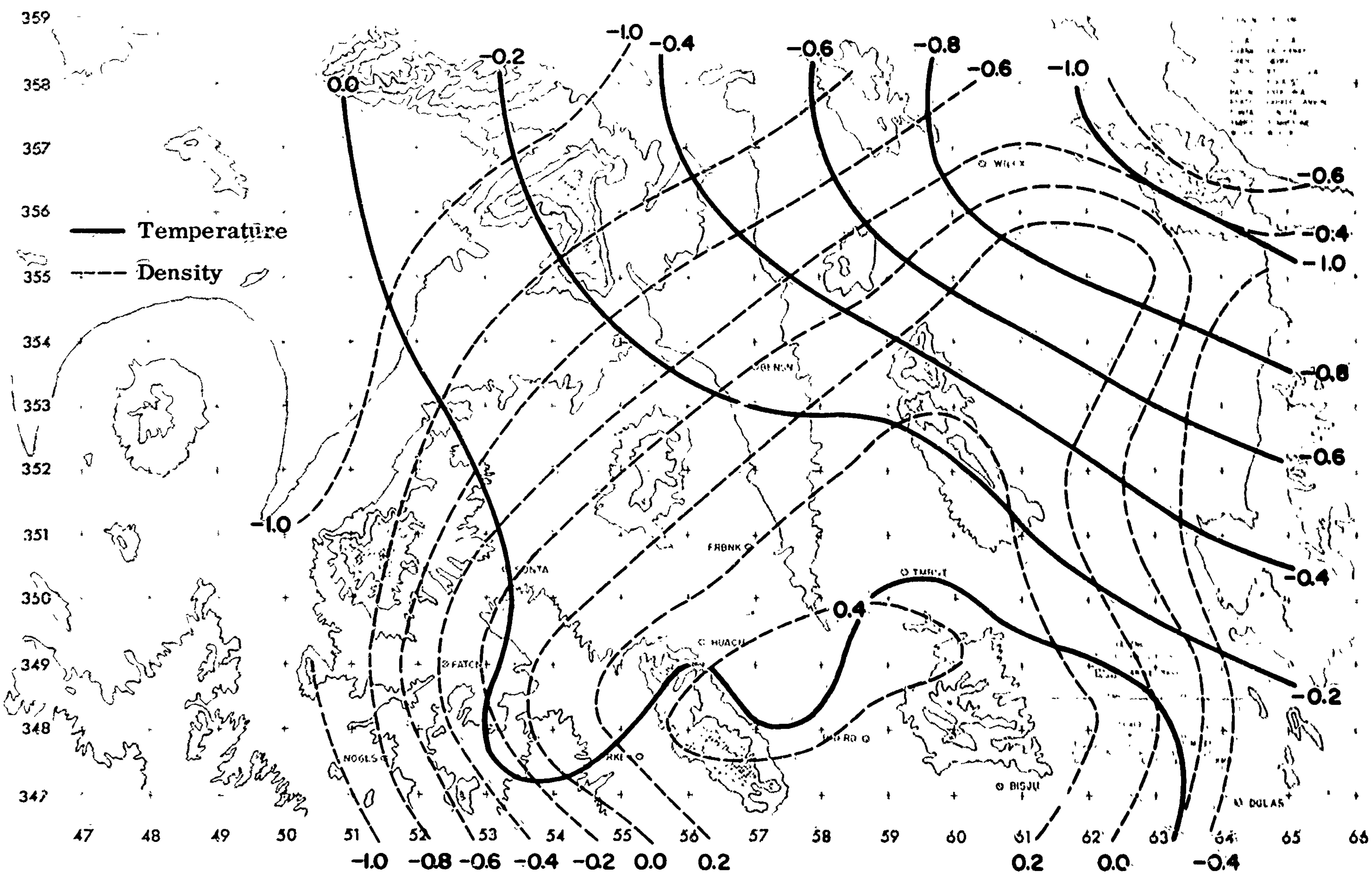

Fig. 2-11. Ballistic temperature and density analysis using CRAM: 1400 MST, 25 January 1965 (percent departure from Standard).

points. Other degrees of smoothing will be tried in the future.

Analyses were produced for each of the ten artillery zones using the procedures outlined above. These zone analyses were then combined into ballistic analyses by computing the weighted sums using the weights given in Table 2-1. Figures 2-2 through 2-6 show the five analyzed fields of ballistic u- and v-wind components (in knots) for 0600, 0800, 1000, 1200, and 1400 MST. The temperature and density analyses are given in Figs. 2-7 through 2-11 (departure from Standard, in percent). The ballistic wind analyses appear much different than those produced by hand in the displaced stations experiment (Figs. 2-7 through 2-11 in Quarterly Report No. 2). This is no doubt due to the fact that no initial guess is used in the hand analyses which leads to a considerable amount of subjectivity in areas of map where there are no data.

The u-component ballistic wind analyses show a gradual weakening trend through the entire map series. A minimum of 84 knots northwest of Douglas can be followed westward map by map reaching an area just west of Ft. Huachuca at 1400 MST. More testing may be required to see if this pattern is realistic or whether it is due to some characteristic of the analysis technique.

Small negative values of the v-component of ballistic wind are present over the southeastern part of the analysis area at 0600 and 0800 MST. At 1000 MST there is a rather sudden change in the eastern part of the region to large negative values which remain for the duration of the series.

The temperature and density analyses (Figs. 2-7 through 2-11) show relatively small gradients with the range of values over an entire map being generally less than 1% of Standard. The temperature values show a cooling trend through the series, reflecting a cooling trend in the upper zones. The surface heating affecting the lower zones does not contribute much to the overall ballistic temperature because of the way the individual zones are weighted (see Table 2-1).

The density fields exhibit increasing gradients during the map series. The maximum values are located in the southern part of the analysis area, with a ridge extending northeastward and becoming more pronounced with time.

The ballistic quantities of u, v, temperature, and density were computed from these analyses at the approximate midpoint of the artillery trajectories and are shown in

Table 2-2. Also shown are those quantities computed from the hand-produced map series contained in Quarterly Report No. 2. In using CRAM, the changes of the values with time in the firing area are generally more gradual than the changes shown by the other analysis methods used. This is due, at least in part, to the incorporation of time in the generation of the initial-guess fields.

Of particular interest is the application of these ballistic corrections to the actual artillery firings that took place at 1000 and 1400 MST for the same day. The provided gun data and unit effects were employed for this purpose. Ballistic temperature and density values were needed to compute the overall correction. These were computed from the CRAM analyses (Figs. 2-9 and 2-11) with the values of 0.34 for temperature and 0.13 for density at 1000 MST and -0.02 for temperature and 0.25 for density at 1400 MST. From fixed station analyses (FXD-1), the values were calculated to be 0.15 and 0.64 at 1000 MST and -0.08 and 0.75 at 1400 MST. Because no values of temperature and density were available from the DISPL and FXD-2 experiments, the FXD-1 values were used for FXD-2 and the CRAM values were used for DISPL. The results are shown in Table 2-3. The target (hypothetical) coordinates are given in meters in

TABLE 2-2
COMPARISON OF BALLISTIC WIND COMPONENTS AT MIDPOINT OF PROJECTILE TRAJECTORY*

Time (MST)	u-component (knots)				v-component (knots)			
	FXD-1	DISPL	FXD-2	CRAM	FXD-1	DISPL	FXD-2	CRAM
0600	86.2	89.7	91.0	90.8	- 7.7	-10.5	- 8.5	-10.7
0800	82.0	77.5	84.0	81.3	- 9.2	-10.8	-16.5	-12.0
1000	72.8	69.2	85.0	74.8	-16.5	-16.7	-21.5	-16.0
1200	70.7	60.3	75.0	68.1	-17.4	-22.2	-23.0	-17.8
1400	64.8	52.2	68.0	61.0	-17.6	-17.5	-20.0	-15.8

*FXD-1: hand analysis based on fixed stations.
FXD-2: hand analysis based on fixed stations, re-analyzed.
DISPL: hand analysis based on radiosonde displacement.
CRAM: analysis based on CRAM objective analysis.

the Universal Transverse Mercator grid system. The range, deflection, and vector errors designated "NO CORRECTIONS" are based on the distance between the target and the center of impact. The range, deflection, and vector errors "WITH CORRECTIONS" refer to the corrected impact point after the drift, coriolis, and meteorological effects have been accounted for. (Negative range errors refer to impact short of the target and negative deflection errors refer to impact to the left of the target when viewed from the gun location.) Also given are the x and y components of the vector error which, when added to the target coordinates, give the coordinates of the corrected impact point. The corrections due to temperature, density, and range wind effect only the range (negative corrections decrease the range), while corrections due to cross wind effect only the deflection (negative corrections displace the impact point to the left). The variability of the residual errors among the several approaches tested is due mainly to the differences in ballistic winds, with the differences due to temperature and density playing a relatively minor role. These residuals are plotted relative to the target in Fig. 2-12. In most of these impacts, the range error is negative for the corrected impact points. It will be shown in the next section that this negative range error was rather anamolous when compared to several other firing situations.

TABLE 2-3
TEST OF METEOROLOGICAL EFFECTS
(25 January 1965, Gun No. 1, AM & PM)

```
  DATE    GUN CASE
25JAN65 A 1   17                  FXD-1 FIXED STATION HAND ANALYSIS

                           -NO CORRECTIONS-       ------WITH  CORRECTIONS--------
      TARGET               VECT.  RANGE DEFLTN  VECT.  RANGE DEFLTN    X       Y
    COORDINATES            ERROR  ERROR  ERROR  ERROR  ERROR  ERROR  COMP.   COMP.
3497847.5N  569430.8E     1827.5  842.5 1621.7  559.3 -444.0  340.1 -337.2 -446.2

METEOR. PARAMETER    METEOR. VALUE    UNIT EFFECT     CORRECTION
   TEMPERATURE              .15         -12.17           -1.83
   DENSITY                  .64          60.40           38.66
   RANGE WIND             65.8          -20.12        -1323.27
   CROSS WIND             35.3          -14.45         -510.17

CORIOLIS CORRECTION=   30.19          DRIFT CORRECTION=  741.19

XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX

  DATE    GUN CASE
25JAN65 A 1   17                  DISPL DISPLACED RADIOSONDE HAND ANALYSIS

                           -NO CORRECTIONS-       ------WITH  CORRECTIONS--------
      TARGET               VECT.  RANGE DEFLTN  VECT.  RANGE DEFLTN    X       Y
    COORDINATES            ERROR  ERROR  ERROR  ERROR  ERROR  ERROR  COMP.   COMP.
3497847.5N  569430.8E     1827.5  842.5 1621.7  537.0 -406.2  351.2 -297.9 -446.8

METEOR. PARAMETER    METEOR. VALUE    UNIT EFFECT     CORRECTION
   TEMPERATURE              .34         -12.17           -4.14
   DENSITY                  .13          60.40            7.85
   RANGE WIND             62.2          -20.12        -1252.39
   CROSS WIND             34.5          -14.45         -499.09

CORIOLIS CORRECTION=   30.19          DRIFT CORRECTION=  741.19
```

TABLE 2-3 (continued)

DATE GUN CASE
25JAN65 A 1 17

FXD-2 RE-ANALYZED FIXED STATION HAND ANALYSIS

TARGET COORDINATES	-NO CORRECTIONS- VECT. ERROR	RANGE ERROR	DEFLTN ERROR	------WITH CORRECTIONS-------- VECT. ERROR	RANGE ERROR	DEFLTN ERROR	X COMP.	Y COMP.
3497847.5N 569430.8E	1827.5	842.5	1621.7	690.9	-653.7	223.5	-570.5	-389.7

METEOR. PARAMETER	METEOR. VALUE	UNIT EFFECT	CORRECTION
TEMPERATURE	.15	-12.17	-1.83
DENSITY	.64	60.40	38.66
RANGE WIND	76.2	-20.12	-1533.05
CROSS WIND	43.4	-14.45	-626.79

CORIOLIS CORRECTION= 30.19 DRIFT CORRECTION= 741.19

XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX

DATE GUN CASE
25JAN65 A 1 17

CRAM

TARGET COORDINATES	-NO CORRECTIONS- VECT. ERROR	RANGE ERROR	DEFLTN ERROR	------WITH CORRECTIONS-------- VECT. ERROR	RANGE ERROR	DEFLTN ERROR	X COMP.	Y COMP.
3497847.5N 569430.8E	1827.5	842.5	1621.7	619.7	-518.5	339.4	-409.3	-465.3

METEOR. PARAMETER	METEOR. VALUE	UNIT EFFECT	CORRECTION
TEMPERATURE	.34	-12.17	-4.14
DENSITY	.13	60.40	7.85
RANGE WIND	67.8	-20.12	-1364.74
CROSS WIND	35.4	-14.45	-510.91

CORIOLIS CORRECTION= 30.19 DRIFT CORRECTION= 741.19

TABLE 2-3 (continued)

DATE GUN CASE
25JAN65 P 1 19

FXD-1 FIXED STATION HAND ANALYSIS

		-NO CORRECTIONS-		------WITH CORRECTIONS--------				
TARGET COORDINATES	VECT. ERROR	RANGE ERROR	DEFLTN ERROR	VECT. ERROR	RANGE ERROR	DEFLTN ERROR	X COMP.	Y COMP.
3497850.7N 569442.2E	1698.8	930.7	1421.2	241.4	-186.0	153.9	-138.3	-197.9

METEOR. PARAMETER	METEOR. VALUE	UNIT EFFECT	CORRECTION
TEMPERATURE	-.08	-8.98	.72
DENSITY	.75	60.51	45.38
RANGE WIND	57.8	-20.13	-1162.82
CROSS WIND	34.2	-14.46	-495.02

CORIOLIS CORRECTION= 30.23 DRIFT CORRECTION= 742.00

XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX

DATE GUN CASE
25JAN65 P 1 19

DISPL DISPLACED RADIOSONDE HAND ANALYSIS

		-NO CORRECTIONS-		------WITH CORRECTIONS--------				
TARGET COORDINATES	VECT. ERROR	RANGE ERROR	DEFLTN ERROR	VECT. ERROR	RANGE ERROR	DEFLTN ERROR	X COMP.	Y COMP.
3497850.7N 569442.2E	1698.8	930.7	1421.2	205.6	27.1	203.8	80.4	-189.3

METEOR. PARAMETER	METEOR. VALUE	UNIT EFFECT	CORRECTION
TEMPERATURE	-.02	-8.98	.18
DENSITY	.25	60.51	15.13
RANGE WIND	45.6	-20.13	-918.89
CROSS WIND	30.8	-14.46	-445.07

CORIOLIS CORRECTION= 30.23 DRIFT CORRECTION= 742.00

TABLE 2-3 (continued)

```
 DATE    GUN CASE
25JAN65 P 1   19
                                        FXD-2 RE-ANALYZED FIXED STATION HAND ANALYSIS

                               -NO CORRECTIONS-         ------WITH  CORRECTIONS--------
      TARGET                 VECT.  RANGE DEFLTN  VECT.  RANGE DEFLTN    X       Y
    COORDINATES              ERROR  ERROR  ERROR  ERROR  ERROR  ERROR   COMP.   COMP.
3497850.7N  569442.2E        1698.8  930.7 1421.2  258.9 -235.2  108.1 -197.9  -166.9

METEOR. PARAMETER       METEOR. VALUE      UNIT EFFECT       CORRECTION
   TEMPERATURE                -.08             -8.98              .72
   DENSITY                     .75             60.51            45.38
   RANGE WIND                60.2             -20.13          -1212.02
   CROSS WIND                37.4             -14.46           -540.81

CORIOLIS CORRECTION=    30.23             DRIFT CORRECTION=   742.00

XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXYXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX

 DATE    GUN CASE
25JAN65 P 1   19                         CRAM

                               -NO CORRECTIONS-         ------WITH  CORRECTIONS--------
      TARGET                 VECT.  RANGE DEFLTN  VECT.  RANGE DEFLTN    X       Y
    COORDINATES              ERROR  ERROR  ERROR  ERROR  ERROR  ERROR   COMP.   COMP.
3497850.7N  569442.2E        1698.8  930.7 1421.2  246.6 -152.8  193.6  -95.6  -227.3

METEOR. PARAMETER       METEOR. VALUE      UNIT EFFECT       CORRECTION
   TEMPERATURE                -.02             -8.98              .18
   DENSITY                     .25             60.51            15.13
   RANGE WIND                54.6             -20.13          -1098.75
   CROSS WIND                31.5             -14.46           -455.29

CORIOLIS CORRECTION=    30.23             DRIFT CORRECTION=   742.00
```

TABLE 2-3 (continued)

DATE	GUN	CASE	
25JAN65	P 1	19	HUACH SINGLE STATION

TARGET COORDINATES		-NO CORRECTIONS- VECT. ERROR	RANGE ERROR	DEFLTN ERROR	------WITH CORRECTIONS-------- VECT. ERROR	RANGL ERROR	DEFLTN ERROR	X COMP.	Y COMP.
3497850.7N	569442.2E	1698.8	930.7	1421.2	238.8	-192.5	141.2	-147.9	-187.4

METEOR. PARAMETER	METEOR. VALUE	UNIT EFFECT	CORRECTION
TEMPERATURE	-.08	-8.98	.72
DENSITY	.70	60.51	42.36
RANGE WIND	57.9	-20.13	-1166.28
CROSS WIND	35.1	-14.46	-507.72

CORIOLIS CORRECTION= 30.23 DRIFT CORRECTION= 742.00

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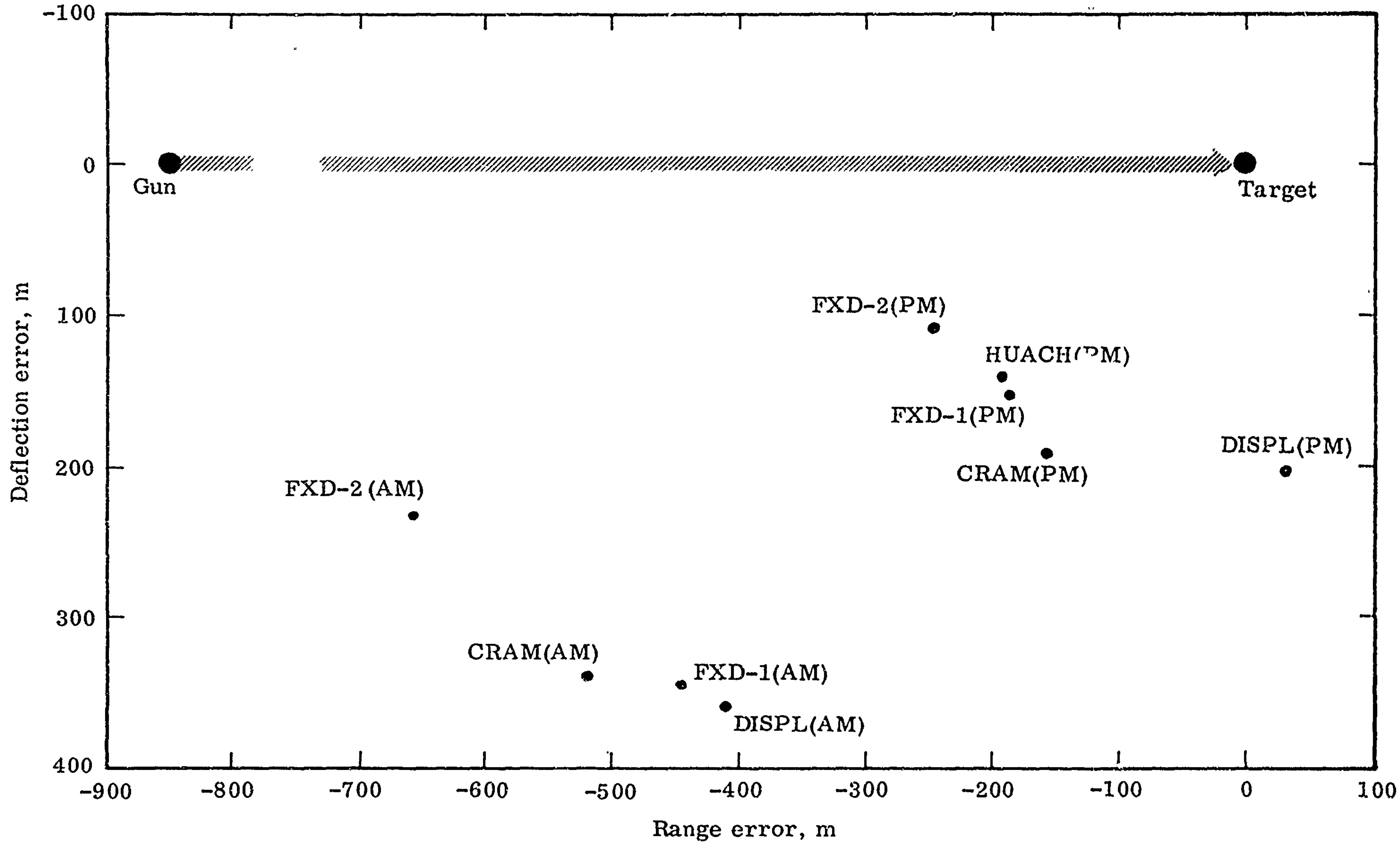

Fig. 2-12. Residual errors for 1000 MST (AM) and 1400 MST (PM) firings (Gun No. 1) on 25 January 1965 using corrections based on various analysis procedures (from Table 2-3).

3.0 CORRECTIONS BASED ON A SINGLE STATION

A small computer program was written for the IBM 1620 which makes the necessary geometrical and trigonometrical steps to systematically modify a given impact point with given meteorological parameters and unit effects in order to yield a corrected impact point. The program prints out the corrections and the various error statistics. By computing this information for all available firing times and using the Ft. Huachuca sounding as the only basis for computing meteorological questions, the resulting data could be used to study the general pattern of the impact points. The data also provided a useful control in comparing results from the objective analysis technique.

The gun data resulted from the firings of two 8-inch howitzers, each firing about ten rounds, alternatively, at one minute intervals. For a given day there were two firing times: 1000 MST and 1400 MST. The locations of the individual impact points were averaged to give a center of impact (CI) for each gun's firing. These data were supplied by the sponsor. The coordinates of the two guns and their azimuths are as follows:

Gun No. 1:	3493987.7N	555472.8E	1325.2 mils, Grid North
Gun No. 2:	3494002.5N	555469.4E	1322.8 mils, Grid North

Of the 24 firing times, there were 19 for which the Ft. Huachuca sounding yielded line-10 ballistic data. The corrections were applied to the appropriate CI's by using the IBM 1620 program written for that purpose. The results are given in Table 3-1 and in Figs. 3-1 and 3-2, which show the corrected CI's relative to the target. It is immediately obvious that there is a preponderance of corrected impact points for which the range error is positive (too long). The reason for this is not known at the present time. There does not appear to be any noticeable bias in the deflection errors. Table 3-2 shows a summary of the error statistics. In addition to the range bias, the total shows that there is no appreciable difference in errors resulting from Gun No. 1 and Gun No. 2 firings.

TABLE 3-1
ARTILLERY CORRECTIONS BASED ON FT. HUACHUCA
METEOROLOGICAL SOUNDINGS*

```
  DATE    GUN CASE
16JAN65 A 1    1                HUACH 10 ZONES FIXED STATION

                         -NO CORRECTIONS-       ------WITH  CORRECTIONS--------
     TARGET            VECT.  RANGE  DEFLTN  VECT.  RANGE  DEFLTN   X      Y
   COORDINATES         ERROR  ERROR  ERROR   ERROR  ERROR  ERROR   COMP.  COMP.
3497838.8N  569399.2E  812.2  403.6  704.9   307.7  304.4   45.4   305.5   37.4

METEOR. PARAMETER     METEOR. VALUE     UNIT EFFECT      CORRECTION
  TEMPERATURE              3.38           -12.25           -41.41
  DENSITY                  -.23            67.45           -15.51
  RANGE WIND               2.1            -20.07           -42.26
  CROSS WIND              -7.6            -14.40           109.65

CORIOLIS CORRECTION=   30.09          DRIFT CORRECTION=  739.01

XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX

  DATE    GUN CASE
16JAN65 A 2    2                HUACH 10 ZONES FIXED STATION

                         -NO CORRECTIONS-       ------WITH  CORRECTIONS--------
     TARGET            VECT.  RANGE  DEFLTN  VECT.  RANGE  DEFLTN   X      Y
   COORDINATES         ERROR  ERROR  ERROR   ERROR  ERROR  ERROR   COMP.  COMP.
3497867.7N  569320.2E  798.9  410.7  685.3   312.4  311.4   24.4   306.5   60.2

METEOR. PARAMETER     METEOR. VALUE     UNIT EFFECT      CORRECTION
  TEMPERATURE              3.38           -12.21           -41.27
  DENSITY                  -.23            67.16           -15.45
  RANGE WIND               2.1            -20.03           -42.53
  CROSS WIND              -7.6            -14.41           109.65

CORIOLIS CORRECTION=   29.80          DRIFT CORRECTION=  740.77
```

*Ft. Huachuca soundings were not available for Cases 11, 12, 13, 14, 17, 18, 31, 32, 41, and 42.

TABLE 3-1 (continued)

DATE GUN CASE
16JAN65 P 1 3

HUACH 10 ZONES FIXED STATION

TARGET COORDINATES		-NO CORRECTIONS- VECT. ERROR	RANGE ERROR	DEFLTN ERROR	------WITH CORRECTIONS-------- VECT. ERROR	RANGE ERROR	DEFLTN ERROR	X COMP.	Y COMP.
3497872.5N	569520.9E	790.1	364.4	701.0	263.2	243.0	-101.2	207.2	162.3

METEOR. PARAMETER	METEOR. VALUE	UNIT EFFECT	CORRECTION
TEMPERATURE	3.65	-11.90	-43.44
DENSITY	-.69	68.67	-47.38
RANGE WIND	1.5	-20.25	-30.61
CROSS WIND	1.7	-14.58	-24.25

CORIOLIS CORRECTION= 30.48 DRIFT CORRECTION= 747.44

XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX

DATE GUN CASE
16JAN65 P 2 4

HUACH 10 ZONES FIXED STATION

TARGET COORDINATES		-NO CORRECTIONS- VECT. ERROR	RANGE ERROR	DEFLTN ERROR	------WITH CORRECTIONS-------- VECT. ERROR	RANGE ERROR	DEFLTN ERROR	X COMP.	Y COMP.
3497883.8N	569378.0E	797.0	409.2	684.0	310.3	288.2	-115.0	246.6	188.2

METEOR. PARAMETER	METEOR. VALUE	UNIT EFFECT	CORRECTION
TEMPERATURE	3.65	-12.04	-43.95
DENSITY	-.69	67.74	-46.74
RANGE WIND	1.5	-20.12	-30.33
CROSS WIND	1.7	-14.50	-24.16

CORIOLIS CORRECTION= 29.99 DRIFT CORRECTION= 744.81

TABLE 3-1 (continued)

```
  DATE    GUN CASE
18JAN65 A 1    5                  HUACH 10 ZONES FIXED STATION

                              -NO CORRECTIONS-       ------WITH  CORRECTIONS--------
      TARGET                VECT.  RANGE DEFLTN  VECT.  RANGE DEFLTN    X       Y
   COORDINATES              ERROR  ERROR  ERROR  ERROR  ERROR  ERROR  COMP.   COMP.
3497865.0N  569494.0E      1092.7  500.2  971.4  305.3  296.0  -74.9  265.3   151.1

METEOR. PARAMETER      METEOR. VALUE     UNIT EFFECT      CORRECTION
   TEMPERATURE              4.16           -11.98           -49.84
   DENSITY                  -.68            68.40           -46.51
   RANGE WIND               5.3            -20.21          -107.86
   CROSS WIND               18.6           -14.54          -270.37

CORIOLIS CORRECTION=    30.40            DRIFT CORRECTION=  745.57

XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX

  DATE    GUN CASE
18JAN65 A 2    6                  HUACH 10 ZONES FIXED STATION

                              -NO CORRECTIONS-       ------WITH  CORRECTIONS--------
      TARGET                VECT.  RANGE DEFLTN  VECT.  RANGE DEFLTN    X       Y
   COORDINATES              ERROR  ERROR  ERROR  ERROR  ERROR  ERROR  COMP.   COMP.
3497882.1N  569371.7E      1073.8  540.8  927.6  357.6  338.2 -116.4  294.4   203.0

METEOR. PARAMETER      METEOR. VALUE     UNIT EFFECT      CORRECTION
   TEMPERATURE              4.16           -12.07           -50.21
   DENSITY                  -.68            67.68           -46.02
   RANGE WIND               5.3            -20.11          -106.45
   CROSS WIND               18.6           -14.49          -269.62

CORIOLIS CORRECTION=    29.97            DRIFT CORRECTION=  744.37
```

TABLE 3-1 (continued)

DATE	GUN	CASE
18JAN65	P 1	7

HUACH 10 ZONES FIXED STATION

TARGET COORDINATES	-NO CORRECTIONS- VECT. ERROR	RANGE ERROR	DEFLTN ERROR	------WITH CORRECTIONS-------- VECT. ERROR	RANGE ERROR	DEFLTN ERROR	X COMP.	Y COMP.
3497874.0N 569526.7E	1106.2	620.8	915.6	240.9	240.3	-16.1	227.4	79.5

METEOR. PARAMETER	METEOR. VALUE	UNIT EFFECT	CORRECTION
TEMPERATURE	4.14	-11.86	-49.10
DENSITY	-1.03	68.77	-70.83
RANGE WIND	12.9	-20.25	-260.51
CROSS WIND	10.5	-14.58	-153.22

CORIOLIS CORRECTION= 30.48 DRIFT CORRECTION= 747.92

XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXY

DATE	GUN	CASE
18JAN65	P 2	8

HUACH 10 ZONES FIXED STATION

TARGET COORDINATES	-NO CORRECTIONS- VECT. ERROR	RANGE ERROR	DEFLTN ERROR	------WITH CORRECTIONS-------- VECT. ERROR	RANGE ERROR	DEFLTN ERROR	X COMP.	Y COMP.
3497899.3N 569433.6E	1060.3	605.8	870.2	235.2	226.8	-62.3	201.7	121.0

METEOR. PARAMETER	METEOR. VALUE	UNIT EFFECT	CORRECTION
TEMPERATURE	4.14	-11.90	-49.27
DENSITY	-1.03	68.28	-70.33
RANGE WIND	12.8	-20.20	-259.36
CROSS WIND	10.5	-14.58	-153.66

CORIOLIS CORRECTION= 30.18 DRIFT CORRECTION= 748.65

TABLE 3-1 (continued)

```
  DATE    GUN CASE
20JAN65 A 1    9                       HUACH 10 ZONES FIXED STATION

                            -NO CORRECTIONS-        ------WITH  CORRECTIONS--------
       TARGET              VECT.  RANGE  DEFLTN  VECT.  RANGE  DEFLTN    X       Y
     COORDINATES           ERROR  ERROR  ERROR   ERROR  ERROR  ERROR   COMP.   COMP.
3497867.6N  569503.3E     1204.2  989.6  686.2   140.4  133.0   45.2   140.2    -8.1

METEOR. PARAMETER     METEOR. VALUE     UNIT EFFECT       CORRECTION
   TEMPERATURE              .22           -11.96             -2.63
   DENSITY                 -.16            68.49            -10.96
   RANGE WIND              41.7           -20.22           -843.04
   CROSS WIND              -9.3           -14.55            135.68

CORIOLIS CORRECTION=   30.43            DRIFT CORRECTION=  746.22

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  DATE    GUN CASE
20JAN65 A 2   10                       HUACH 10 ZONES FIXED STATION

                            -NO CORRECTIONS-        ------WITH  CORRECTIONS--------
       TARGET              VECT.  RANGE  DEFLTN  VECT.  RANGE  DEFLTN    X       Y
     COORDINATES           ERROR  ERROR  ERROR   ERROR  ERROR  ERROR   COMP.   COMP.
3497893.4N  569412.2E     1155.1  959.0  643.9   104.1  104.1     .8   100.5    27.2

METEOR. PARAMETER     METEOR. VALUE     UNIT EFFECT       CORRECTION
   TEMPERATURE              .22           -11.95             -2.63
   DENSITY                 -.16            68.08            -10.89
   RANGE WIND              41.7           -20.17           -841.40
   CROSS WIND              -9.2           -14.55            134.25

CORIOLIS CORRECTION=   30.10            DRIFT CORRECTION=  747.19
```

TABLE 3-1 (continued)

```
 DATE   GUN CASE
22JAN65 P 1  15                 HUACH 10 ZONES FIXED STATION

                           -NO CORRECTIONS-      ------WITH  CORRECTIONS--------
     TARGET               VECT.  RANGE DEFLTN  VECT.  RANGE DEFLTN    X      Y
   COORDINATES            ERROR  ERROR  ERROR  ERROR  ERROR  ERROR  COMP.  COMP.
3497867.3N  569502.2E    1673.1  948.8 1378.0  645.9  556.3 -328.2  448.7  464.9

METEOR. PARAMETER     METEOR. VALUE    UNIT EFFECT     CORRECTION
   TEMPERATURE             -.15          -8.77            1.32
   DENSITY                  .24          61.01           14.64
   RANGE WIND             20.2          -20.22         -408.47
   CROSS WIND             63.9          -14.55         -929.68

CORIOLIS CORRECTION=   30.43         DRIFT CORRECTION=  746.13

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 DATE   GUN CASE
22JAN65 P 2  16                 HUACH 10 ZONES FIXED STATION

                           -NO CORRECTIONS-      ------WITH  CORRECTIONS--------
     TARGET               VECT.  RANGE DEFLTN  VECT.  RANGE DEFLTN    X      Y
   COORDINATES            ERROR  ERROR  ERROR  ERROR  ERROR  ERROR  COMP.  COMP.
3497877.0N  569353.4E    1663.1  981.9 1342.3  693.1  595.1 -355.3  477.7  502.1

METEOR. PARAMETER     METEOR. VALUE    UNIT EFFECT     CORRECTION
   TEMPERATURE             -.15          -8.98            1.35
   DENSITY                  .24          60.15           14.44
   RANGE WIND             20.1          -20.08         -402.61
   CROSS WIND             63.9          -14.46         -924.61

CORIOLIS CORRECTION=   29.91         DRIFT CORRECTION=  743.08
```

TABLE 3-1 (continued)

```
 DATE    GUN CASE
25JAN65 P 1   19                    HUACH 10 ZONES FIXED STATION

                           -NO CORRECTIONS-      ------WITH  CORRECTIONS--------
      TARGET              VECT.  RANGE DEFLTN  VECT.  RANGE DEFLTN     X       Y
    COORDINATES           ERROR  ERROR  ERROR  ERROR  ERROR  ERROR   COMP.   COMP.
3497850.7N  569442.2E    1698.8  930.7 1421.2  238.8 -192.5  141.2  -147.9  -187.4

METEOR. PARAMETER     METEOR. VALUE    UNIT EFFECT      CORRECTION
    TEMPERATURE            -.08           -8.98             .72
    DENSITY                 .70           60.51           42.36
    RANGE WIND             57.9          -20.13        -1166.28
    CROSS WIND             35.1          -14.46         -507.72

CORIOLIS CORRECTION=     30.23          DRIFT CORRECTION=   742.00

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 DATE    GUN CASE
25JAN65 P 2   20                    HUACH 10 ZONES FIXED STATION

                           -NO CORRECTIONS-      ------WITH  CORRECTIONS--------
      TARGET              VECT.  RANGE DEFLTN  VECT.  RANGE DEFLTN     X       Y
    COORDINATES           ERROR  ERROR  ERROR  ERROR  ERROR  ERROR   COMP.   COMP.
3497849.9N  569256.5E    1651.3  957.0 1345.7  171.1 -153.8   75.0  -128.0  -113.5

METEOR. PARAMETER     METEOR. VALUE    UNIT EFFECT      CORRECTION
    TEMPERATURE            -.08           -9.33             .75
    DENSITY                 .70           59.34           41.54
    RANGE WIND             57.9          -19.93        -1153.04
    CROSS WIND             35.2          -14.32         -504.75

CORIOLIS CORRECTION=     29.60          DRIFT CORRECTION=   736.35
```

TABLE 3-1 (continued)

```
  DATE    GUN CASE
27JAN65 A 1   21                HUACH 10 ZONES FIXED STATION

                              -NO CORRECTIONS-      ------WITH  CORRECTIONS--------
        TARGET               VECT.  RANGE DEFLTN  VECT.  RANGE DEFLTN    X       Y
      COORDINATES            ERROR  ERROR  ERROR  ERROR  ERROR  ERROR  COMP.   COMP.
3497841.3N  569408.3E       1121.1  373.5 1057.1  197.9  197.8    7.3  192.6    45.7

METEOR. PARAMETER      METEOR. VALUE     UNIT EFFECT      CORRECTION
   TEMPERATURE                 .19          -12.22           -2.32
   DENSITY                    1.66           60.22           99.97
   RANGE WIND                13.6           -20.08         -273.36
   CROSS WIND                19.4           -14.41         -280.00

CORIOLIS CORRECTION=    30.12           DRIFT CORRECTION=   739.65

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  DATE    GUN CASE
27JAN65 A 2   22                HUACH 10 ZONES FIXED STATION

                              -NO CORRECTIONS-      ------WITH  CORRECTIONS--------
        TARGET               VECT.  RANGE DEFLTN  VECT.  RANGE DEFLTN    X       Y
      COORDINATES            ERROR  ERROR  ERROR  ERROR  ERROR  ERROR  COMP.   COMP.
3497864.0N  569307.1E       1061.0  397.1  983.9  232.0  222.5  -65.8  196.6   123.1

METEOR. PARAMETER      METEOR. VALUE     UNIT EFFECT      CORRECTION
   TEMPERATURE                 .19          -12.25           -2.33
   DENSITY                    1.66           59.77           99.22
   RANGE WIND                13.6           -20.01         -271.49
   CROSS WIND                19.5           -14.39         -280.08

CORIOLIS CORRECTION=    29.76           DRIFT CORRECTION=   739.87
```

TABLE 3-1 (continued)

DATE GUN CASE
27JAN65 P 1 23

HUACH 10 ZONES FIXED STATION

TARGET COORDINATES	-NO CORRECTIONS- VECT. ERROR	RANGE ERROR	DEFLTN ERROR	------WITH CORRECTIONS-------- VECT. ERROR	RANGE ERROR	DEFLTN ERROR	X COMP.	Y COMP.
3497870.0N 569512.1E	1115.3	508.8	992.5	247.2	234.8	-77.2	205.7	137.0

METEOR. PARAMETER	METEOR. VALUE	UNIT EFFECT	CORRECTION
TEMPERATURE	.33	-11.93	-3.94
DENSITY	.99	61.10	60.49
RANGE WIND	16.3	-20.23	-330.54
CROSS WIND	20.1	-14.56	-292.38

CORIOLIS CORRECTION= 30.45 DRIFT CORRECTION= 746.84

XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX

DATE GUN CASE
27JAN65 P 2 24

HUACH 10 ZONES FIXED STATION

TARGET COORDINATES	-NO CORRECTIONS- VECT. ERROR	RANGE ERROR	DEFLTN ERROR	------WITH CORRECTIONS-------- VECT. ERROR	RANGE ERROR	DEFLTN ERROR	X COMP.	Y COMP.
3497886.6N 569388.0E	1088.7	541.0	944.8	295.6	268.9	-122.7	226.1	190.5

METEOR. PARAMETER	METEOR. VALUE	UNIT EFFECT	CORRECTION
TEMPERATURE	.33	-12.01	-3.96
DENSITY	.99	60.46	59.86
RANGE WIND	16.3	-20.13	-327.95
CROSS WIND	20.1	-14.51	-291.93

CORIOLIS CORRECTION= 30.02 DRIFT CORRECTION= 745.51

TABLE 3-1 (continued)

```
  DATE    GUN CASE
29JAN65 A 1   25                HUACH 10 ZONES FIXED STATION

                            -NO CORRECTIONS-       ------WITH  CORRECTIONS--------
     TARGET                VECT.  RANGE DEFLTN  VECT.  RANGE DEFLTN     X       Y
   COORDINATES             ERROR  ERROR  ERROR  ERROR  ERROR  ERROR  COMP.   COMP.
3497843.5N  569416.3E      882.6  195.4  860.7  462.1  460.6   37.9  454.0    86.2

METEOR. PARAMETER    METEOR. VALUE    UNIT EFFECT     CORRECTION
   TEMPERATURE            1.79           -12.20          -21.84
   DENSITY                -.03            67.63           -2.03
   RANGE WIND            -13.9           -20.84          289.06
   CROSS WIND              3.6           -14.42          -52.41

CORIOLIS CORRECTION=   30.14         DRIFT CORRECTION=  740.21

XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX

  DATE    GUN CASE
29JAN65 A 2   26                HUACH 10 ZONES FIXED STATION

                            -NO CORRECTIONS-       ------WITH  CORRECTIONS--------
     TARGET                VECT.  RANGE DEFLTN  VECT.  RANGE DEFLTN     X       Y
   COORDINATES             ERROR  ERROR  ERROR  ERROR  ERROR  ERROR  COMP.   COMP.
3497860.1N  569292.9E      850.3  200.4  826.4  464.3  464.3    6.0  448.8   119.0

METEOR. PARAMETER    METEOR. VALUE    UNIT EFFECT     CORRECTION
   TEMPERATURE            1.79           -12.28          -21.98
   DENSITY                -.03            66.90           -2.01
   RANGE WIND            -13.9           -20.74          287.85
   CROSS WIND              3.6           -14.37          -51.76

CORIOLIS CORRECTION=   29.71         DRIFT CORRECTION=  738.88
```

TABLE 3-1 (continued)

DATE	GUN	CASE
29JAN65	P 1	27

HUACH 10 ZONES FIXED STATION

TARGET COORDINATES	-NO CORRECTIONS- VECT. ERROR	RANGE ERROR	DEFLTN ERROR	------WITH CORRECTIONS-------- VECT. ERROR	RANGE ERROR	DEFLTN ERROR	X COMP.	Y COMP.
3497881.0N 569551.6E	963.2	333.6	903.6	401.2	401.2	4.5	387.9	102.6

METEOR. PARAMETER	METEOR. VALUE	UNIT EFFECT	CORRECTION
TEMPERATURE	2.19	-11.81	-25.86
DENSITY	-.66	68.98	-45.53
RANGE WIND	-6.6	-21.04	139.01
CROSS WIND	8.1	-14.62	-118.91

CORIOLIS CORRECTION= 30.58 DRIFT CORRECTION= 749.58

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DATE	GUN	CASE
29JAN65	P 2	28

HUACH 10 ZONES FIXED STATION

TARGET COORDINATES	-NO CORRECTIONS- VECT. ERROR	RANGE ERROR	DEFLTN ERROR	------WITH CORRECTIONS-------- VECT. ERROR	RANGE ERROR	DEFLTN ERROR	X COMP.	Y COMP.
3497896.3N 569422.8E	919.6	338.9	854.9	408.6	406.5	-41.4	380.4	149.1

METEOR. PARAMETER	METEOR. VALUE	UNIT EFFECT	CORRECTION
TEMPERATURE	2.19	-11.91	-26.08
DENSITY	-.66	68.19	-45.01
RANGE WIND	-6.6	-20.93	138.68
CROSS WIND	8.1	-14.56	-118.19

CORIOLIS CORRECTION= 30.13 DRIFT CORRECTION= 747.94

TABLE 3-1 (continued)

```
  DATE    GUN CASE
02FEB65 A 1   29                  HUACH 10 ZONES FIXED STATION

                          -NO CORRECTIONS-       ------WITH  CORRECTIONS--------
      TARGET              VECT.  RANGE DEFLTN  VECT.  RANGE DEFLTN    X       Y
    COORDINATES           ERROR  ERROR  ERROR  ERROR  ERROR  ERROR  COMP.   COMP.
3497868.0N  569504.9E     754.9  442.0  611.9  257.9  -64.2  249.7    4.6  -257.8

METEOR. PARAMETER    METEOR. VALUE    UNIT EFFECT     CORRECTION
   TEMPERATURE            1.85          -11.95         -22.11
   DENSITY                -.27           58.51         -18.50
   RANGE WIND             23.0          -20.22        -465.61
   CROSS WIND            -28.5          -14.55         414.58

CORIOLIS CORRECTION=   30.43          DRIFT CORRECTION=  746.34

XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX

  DATE    GUN CASE
02FEB65 A 2   30                  HUACH 10 ZONES FIXED STATION

                          -NO CORRECTIONS-       ------WITH  CORRECTIONS--------
      TARGET   .          VECT.  RANGE DEFLTN  VECT.  RANGE DEFLTN    X       Y
    COORDINATES           ERROR  ERROR  ERROR  ERROR  ERROR  ERROR  COMP.   COMP.
3497882.4N  569372.8E     733.4  447.5  581.1  226.2  -57.5  218.7    3.4  -226.1

METEOR. PARAMETER    METEOR. VALUE    UNIT EFFECT     CORRECTION
   TEMPERATURE            1.85          -12.05         -22.29
   DENSITY                -.27           67.69         -18.28
   RANGE WIND             23.1          -20.11        -464.42
   CROSS WIND            -28.4          -14.49         412.08

CORIOLIS CORRECTION=   29.97          DRIFT CORRECTION=  744.45
```

TABLE 3-1 (continued)

DATE	GUN	CASE
04FEB65	A 1	33

HUACH 10 ZONES FIXED STATION

TARGET COORDINATES	-NO CORRECTIONS- VECT. ERROR	RANGE ERROR	DEFLTN ERROR	------WITH CORRECTIONS-------- VECT. ERROR	RANGE ERROR	DEFLTN ERROR	X COMP.	Y COMP.
3497880.5N 569549.8E	779.6	122.4	770.0	204.8	203.7	-21.0	190.8	74.5

METEOR. PARAMETER	METEOR. VALUE	UNIT EFFECT	CORRECTION
TEMPERATURE	2.23	-11.82	-26.36
DENSITY	-.02	68.97	-1.38
RANGE WIND	-5.2	-21.04	109.12
CROSS WIND	.7	-14.62	-10.89

CORIOLIS CORRECTION= 30.57 DRIFT CORRECTION= 749.46

XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX

DATE	GUN	CASE
04FEB65	A 2	34

HUACH 10 ZONES FIXED STATION

TARGET COORDINATES	-NO CORRECTIONS- VECT. ERROR	RANGE ERROR	DEFLTN ERROR	------WITH CORRECTIONS-------- VECT. ERROR	RANGE ERROR	DEFLTN ERROR	X COMP.	Y COMP.
3497887.9N 569392.4E	765.5	184.7	742.9	268.5	264.9	-43.6	243.5	113.2

METEOR. PARAMETER	METEOR. VALUE	UNIT EFFECT	CORRECTION
TEMPERATURE	2.23	-12.00	-26.76
DENSITY	-.02	67.89	-1.36
RANGE WIND	-5.2	-20.89	108.37
CROSS WIND	.7	-14.52	-10.64

CORIOLIS CORRECTION= 30.03 DRIFT CORRECTION= 745.82

TABLE 3-1 (continued)

```
  DATE    GUN CASE
04FEB65 P 1   35                 HUACH 10 ZONES FIXED STATION

                              -NO CORRECTIONS-       ------WITH  CORRECTIONS--------
        TARGET              VECT.  RANGE  DEFLTN   VECT.  RANGE  DEFLTN    X       Y
      COORDINATES           ERROR  ERROR  ERROR    ERROR  ERROR  ERROR   COMP.   COMP.
3497892.4N   569593.1E      790.5  225.1  757.8    225.2  223.6   27.0   222.7    33.5

METEOR. PARAMETER      METEOR. VALUE     UNIT EFFECT     CORRECTION
   TEMPERATURE              2.12            -11.69          -24.78
   DENSITY                  -.28             69.40          -19.43
   RANGE WIND               -2.0            -21.10           42.67
   CROSS WIND               -3.6            -14.68           52.38

CORIOLIS CORRECTION=    30.71            DRIFT CORRECTION=  752.46

XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX

  DATE    GUN CASE
04FEB65 P 2   36                 HUACH 10 ZONES FIXED STATION

                              -NO CORRECTIONS-       ------WITH  CORRECTIONS--------
        TARGET              VECT.  RANGE  DEFLTN   VECT.  RANGE  DEFLTN    X       Y
      COORDINATES           ERROR  ERROR  ERROR    ERROR  ERROR  ERROR   COMP.   COMP.
3497885.4N   569383.5E      785.0  284.3  731.7    282.0  281.8    8.4   273.7    67.7

METEOR. PARAMETER      METEOR. VALUE     UNIT EFFECT     CORRECTION
   TEMPERATURE              2.12            -12.02          -25.48
   DENSITY                  -.28             67.80          -18.98
   RANGE WIND               -2.[illegible]            -20.88           42.05
   CROSS WIND               -3.6            -14.51           51.84

CORIOLIS CORRECTION=    [illegible]            DRIFT CORRECTION=  74[illegible]
```

TABLE 3-1 (continued)

DATE	GUN	CASE
06FEB65	A 1	37

HUACH 10 ZONES FIXED STATION

TARGET COORDINATES	-NO CORRECTIONS- VECT. ERROR	RANGE ERROR	DEFLTN ERROR	------WITH CORRECTIONS-------- VECT. ERROR	RANGE ERROR	DEFLTN ERROR	X COMP.	Y COMP.
3497853.9N 569453.9E	1292.4	1117.5	649.2	63.6	-3[illegible]	55.7	-14.8	-61.9

METEOR. PARAMETER	METEOR. VALUE	UNIT EFFECT	CORRECTION
TEMPERATURE	1.39	-12.09	-16.81
DENSITY	-1.02	68.00	-69.36
RANGE WIND	52.7	-20.15	-1062.14
CROSS WIND	-12.4	-14.48	179.55

CORIOLIS CORRECTION= 30.26 DRIFT CORRECTION= 742.81

XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX

DATE	GUN	CASE
06FEB65	A 2	38

HUACH 10 ZONES FIXED STATION

TARGET COORDINATES	-NO CORRECTIONS- VECT. ERROR	RANGE ERROR	DEFLTN ERROR	------WITH CORRECTIONS-------- VECT. ERROR	RANGE ERROR	DEFLTN ERROR	X COMP.	Y COMP.
3497878.9N 569360.3E	1268.4	1098.8	633.6	59.8	-46.5	37.7	-34.6	-48.8

METEOR. PARAMETER	METEOR. VALUE	UNIT EFFECT	CORRECTION
TEMPERATURE	1.39	-12.09	-16.81
DENSITY	-1.02	67.57	-68.92
RANGE WIND	52.7	-20.09	-1059.56
CROSS WIND	-12.3	-14.47	177.63

CORIOLIS CORRECTION= 29.93 DRIFT CORRECTION= 743.58

TABLE 3-1 (continued)

DATE GUN CASE
06FEB65 P 1 39

HUACH 10 ZONES FIXED STATION

TARGET COORDINATES		-NO CORRECTIONS- VECT. ERROR	RANGE ERROR	DEFLTN ERROR	------WITH CORRECTIONS-------- VECT. ERROR	RANGE ERROR	DEFLTN ERROR	X COMP.	Y COMP.
3497849.0N	569436.0E	1523.1	1361.1	683.5	106.1	-62.2	86.0	-37.0	-99.5

METEOR. PARAMETER	METEOR. VALUE	UNIT EFFECT	CORRECTION
TEMPERATURE	-.01	-9.00	.09
DENSITY	-.76	67.82	-51.54
RANGE WIND	68.2	-20.12	-1371.82
CROSS WIND	-12.1	-14.45	174.33

CORIOLIS CORRECTION= 30.21 DRIFT CORRECTION= 741.57

XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX

DATE GUN CASE
06FEB65 P 2 40

HUACH 10 ZONES FIXED STATION

TARGET COORDINATES		-NO CORRECTIONS- VECT. ERROR	RANGE ERROR	DEFLTN ERROR	------WITH CORRECTIONS-------- VECT. ERROR	RANGE ERROR	DEFLTN ERROR	X COMP.	Y COMP.
3497886.9N	569388.9E	1446.4	1276.1	681.0	167.8	-148.5	78.1	-122.0	-115.1

METEOR. PARAMETER	METEOR. VALUE	UNIT EFFECT	CORRECTION
TEMPERATURE	-.01	-8.85	.09
DENSITY	-.76	67.85	-51.57
RANGE WIND	68.2	-20.13	-1373.07
CROSS WIND	-11.9	-14.51	172.72

CORIOLIS CORRECTION= 30.02 DRIFT CORRECTION= 745.57

TABLE 3-1 (continued)

DATE	GUN	CASE
10FEB65	P 1	43

HUACH 10 ZONES FIXED STATION

TARGET COORDINATES		-NO CORRECTIONS-			------WITH CORRECTIONS--------				
		VECT. ERROR	RANGE ERROR	DEFLTN ERROR	VECT. ERROR	RANGE ERROR	DEFLTN ERROR	X COMP.	Y COMP.
3497851.4N	569444.9E	1217.8	888.1	833.3	233.2	-191.4	133.3	-149.0	-179.5

METEOR. PARAMETER	METEOR. VALUE	UNIT EFFECT	CORRECTION
TEMPERATURE	-2.45	-8.97	21.98
DENSITY	.86	60.53	52.06
RANGE WIND	57.3	-20.13	-1153.60
CROSS WIND	-5.0	-14.47	72.46

CORIOLIS CORRECTION= 30.24 DRIFT CORRECTION= 742.'9

XXXXXXXXXXXXXXXXXXXXXXXXXXXXXYXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX) XXXXXXXXXXXXXX

DATE	GUN	CASE
10FEB65	P 2	44

HUACH 10 ZONES FIXED STATION

TARGET COORDINATES		-NO CORRECTIONS-			------WITH CORRECTIONS--------				
		VECT. ERROR	RANGE ERROR	DEFLTN ERROR	VECT. ERROR	RANGE ERROR	DEFLTN ERROR	X COMP.	Y COMP.
3497871.2N	569332.8E	1184.8	861.2	813.6	242.0	-214.3	112.4	-176.2	-165.9

METEOR. PARAMETER	METEOR. VALUE	UNIT EFFECT	CORRECTION
TEMPERATURE	-2.45	-9.05	22.17
DENSITY	.86	59.98	51.58
RANGE WIND	57.3	-20.05	-1149.25
CROSS WIND	-4.9	-14.43	70.31

CORIOLIS CORRECTION= 29.84 DRIFT CORRECTION= 741.66

TABLE 3-1 (continued)

```
  DATE    GUN CASE
12FEB65 A 1   45                HUACH 10 ZONES FIXED STATION

                              -NO CORRECTIONS-      ------WITH  CORRECTIONS--------
       TARGET               VECT.  RANGE DEFLTN  VECT.  RANGE DEFLTN    X       Y
     COORDINATES            ERROR  ERROR  ERROR  ERROR  ERROR  ERROR  COMP.   COMP.
3497848.0N  569432.4E       1137.0  419.1 1056.9  266.7  260.8  -55.6  236.6   123.1

METEOR. PARAMETER     METEOR. VALUE     UNIT EFFECT      CORRECTION
   TEMPERATURE             -1.99            -9.01            17.93
   DENSITY                  1.51            60.43            91.25
   RANGE WIND              13.3            -20.12          -267.43
   CROSS WIND              23.6            -14.45          -340.96

CORIOLIS CORRECTION=    30.20           DRIFT CORRECTION=  741.32

XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXYXXXXXYXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX

  DATE    GUN CASE
12FEB65 A 2   46                HUACH 10 ZONES FIXED STATION

                              -NO CORRECTIONS-      ------WITH  CORRECTIONS--------
       TARGET               VECT.  RANGE DEFLTN  VECT.  RANGE DEFLTN    X       Y
     COORDINATES            ERROR  ERROR  ERROR  ERROR  ERROR  ERROR  COMP.   COMP.
3497867.0N  569317.7E       1119.4  402.3 1044.6  254.5  245.7  -66.3  218.9   129.9

METEOR. PARAMETER     METEOR. VALUE     UNIT EFFECT      CORRECTION
   TEMPERATURE             -1.99            -9.10            18.11
   DENSITY                  1.51            59.86            90.39
   RANGE WIND              13.2            -20.03          -265.12
   CROSS WIND              23.6            -14.41          -340.47

CORIOLIS CORRECTION=    29.79           DRIFT CORRECTION=  740.61
```

TABLE 3-1 (continued)

DATE GUN CASE
12FEB65 P 1 47

HUACH 10 ZONES FIXED STATION

TARGET COORDINATES	-NO CORRECTIONS- VECT. ERROR	RANGE ERROR	DEFLTN ERROR	------WITH CORRECTIONS-------- VECT. ERROR	RANGE ERROR	DEFLTN ERROR	X COMP.	Y COMP.
3497844.5N 569419.9E	1158.0	345.0	1105.4	350.3	332.5	-110.2	291.1	194.8

METEOR. PARAMETER	METEOR. VALUE	UNIT EFFECT	CORRECTION
TEMPERATURE	-1.57	-9.06	14.22
DENSITY	1.21	60.32	72.99
RANGE WIND	5.0	-20.10	-99.71
CROSS WIND	30.8	-14.43	-444.99

CORIOLIS CORRECTION= 30.16 DRIFT CORRECTION= 741.45

XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX

DATE GUN CASE
12FEB65 P 2 48

HUACH 10 ZONES FIXED STATION

TARGET COORDINATES	-NO CORRECTIONS- VECT. ERROR	RANGE ERROR	DEFLTN ERROR	------WITH CORRECTIONS-------- VECT. ERROR	RANGE ERROR	DEFLTN ERROR	X COMP.	Y COMP.
3497867.7N 569320.4E	1156.4	365.2	1097.2	373.1	354.0	-117.9	309.3	208.7

METEOR. PARAMETER	METEOR. VALUE	UNIT EFFECT	CORRECTION
TEMPERATURE	-1.57	-9.09	14.27
DENSITY	1.21	59.88	72.45
RANGE WIND	4.9	-20.03	-97.90
CROSS WIND	30.8	-14.41	-444.54

CORIOLIS CORRECTION= 29.80 DRIFT CORRECTION= 740.80

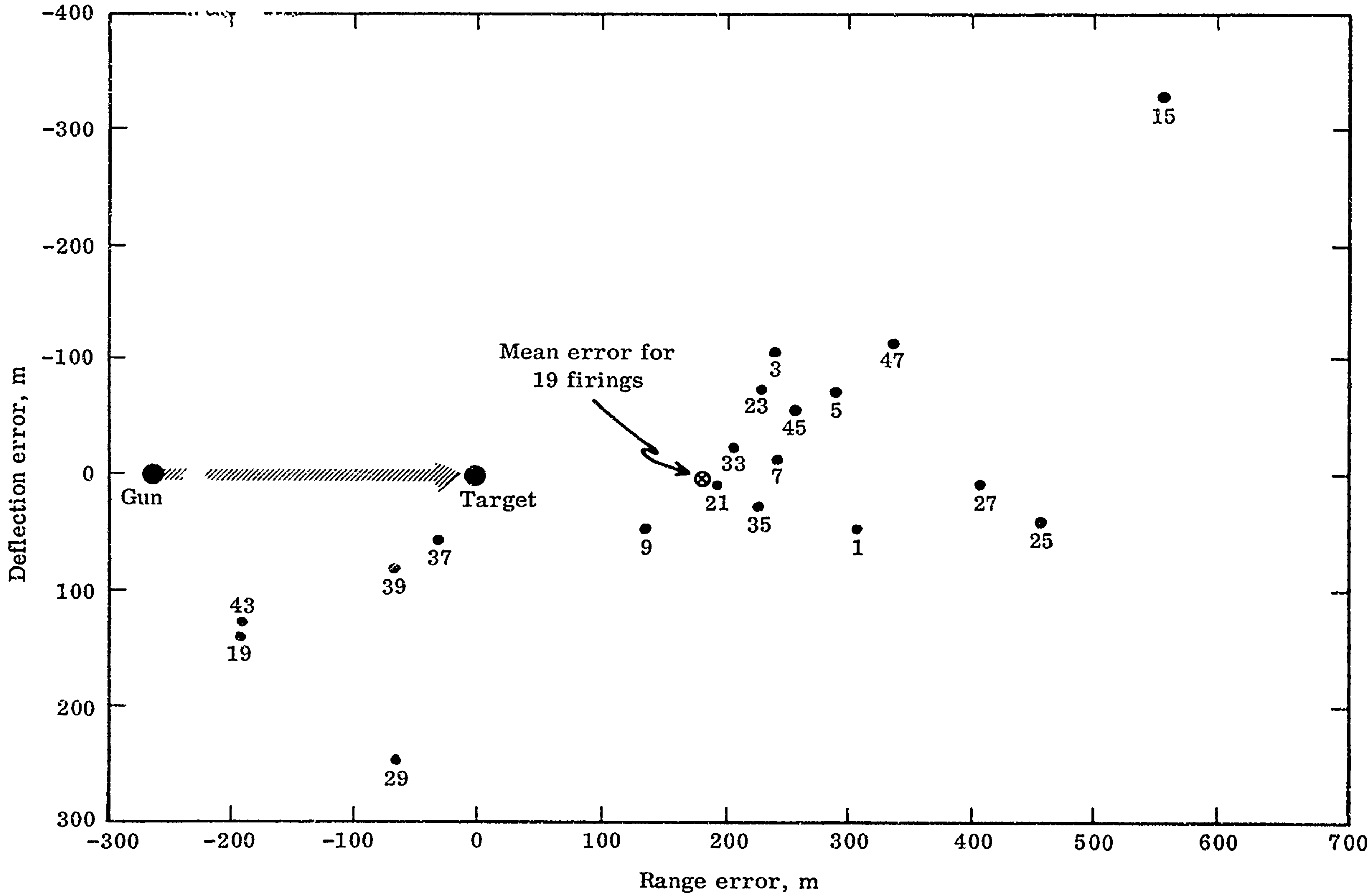

Fig. 3-1. Residual errors for Gun No. 1 firings listed in Table 3-1. Numbers refer to case numbers in table.

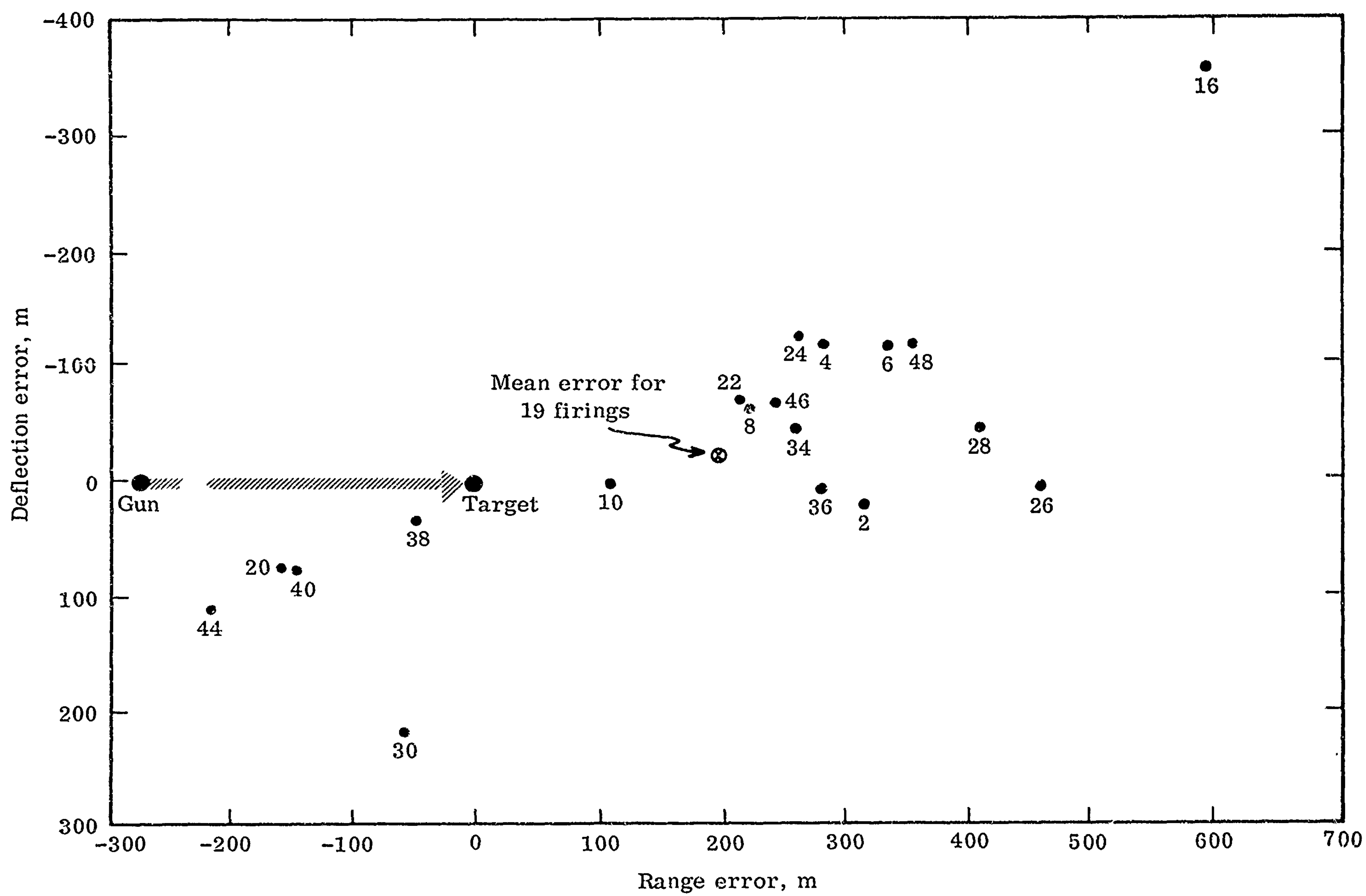

Fig. 3-2. Residual errors for Gun No. 2 firings listed in Table 3-1. Numbers refer to case numbers in table.

TABLE 3-2
SUMMARY OF RESIDUAL ERRORS FROM TABLE 3-1 FOR
19 FIRING TIMES (in m)

Gun no.	Average error (algebraic)		Average error (absolute)		Residual vector error	Location of impacts			
	Range	Deflection	Range	Deflection		Long	Short	Left	Right
1	+187	+ 3	244	85	272	14	5	8	11
2	+198	-29	263	88	287	14	5	10	9

4.0 POST-PROCESSING PROGRAM

A computer program is being written for the IBM 7090 which will be an expanded version of the small IBM 1620 program mentioned in the previous section. It will compute fields of residual errors which can be averaged over a series of maps to determine spatial and temporal variability of artillery corrections. Corrections based on concurrent meteorological effects will be compared with corrections based on such effects 2-, 4-, 6-, and 8-hours old. The change in ballistic quantities from 0600 to 0800 MST will be used to generate a predicted 1000 MST set of ballistic maps which can be used to compute corrections. Likewise, a 1400 MST prediction can be generated from the change between 0600 and 1000 MST as well as the change between 1000 and 1200 MST.

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13. ABSTRACT

An objective analysis technique known as CRAM (Conditional Relaxation Analysis Method) has been programmed for the IBM 7090 to compute ballistic winds, temperature, and density over a region of southeastern Arizona in the vicinity of Ft. Huachuca. The various components and available options of the program are described. A set of analyses produced from initial tests is shown and the ballistic quantities derived are compared with those of the previous quarterly report.

Corrections based on a single station (Ft. Huachuca) were applied to concurrent artillery firings for 19 cases. The residual errors derived from these cases will be used as a control for later experiments. The distribution of the residual errors relative to the target strongly suggests a bias in range errors, the average impact location being nearly 200 meters beyond the target.

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	ROLE	WT	ROLE	WT	ROLE	WT
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